2

Report No. CG-D-09-89

AD-A210 421

POSITIONING EXPERIMENT: SHORT RANGE AIDS/RADIO AIDS PRINCIPAL FINDINGS: WATERWAY PERFORMANCE, DESIGN AND EVALUATION STUDY

Ship Analytics, Inc.
North Stonington Professional Center
North Stonington, CT 06359

INTERIM REPORT
October 1988

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Coast Guard
Research and Development Center
Avery Point
Groton, CT 06340-6096

and

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering and Development
Washington, DC 20593-0001

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research and Development Center, which is responsible for the facts and accuracy of data presented. This report does not constitute a standard, specification, or regulation.

SAMUEL F. POWEL, III
Technical Director
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-09-89	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Positioning Experiment: Short Range Aids/Radio Aids Principal Findings: Waterway Performance Design and Evaluation Study		5. Report Date October 1988
		6. Performing Organization Code
7. Author(s) W.S. Brown, M.W. Smith, and J.A. Conway		8. Performing Organization Report No. 87-U-512 CGR&DC 4/88
9. Performing Organization Name and Address Ship Analytics, Incorporated North Stonington Professional Center North Stonington, Connecticut 06359		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTCG-23-86-C-20030
12. Sponsoring Agency Name and Address U.S. Department of Transportation U.S. Coast Guard Office of Engineering and Development Washington, D.C. 20593		13. Type of Report and Period Covered Interim Report
		14. Sponsoring Agency Code
15. Supplementary Notes U.S. Coast Guard Participants: Mr. K.R. Schroeder/G-DST-1, LCDR H.H. Sharpe/G-NSR-1, LCDR W.R. Ridley/G-DST-1, Dr. M.B. Mandler/R&D Center		

16. Abstract

This report describes one of a series of man-in-the-loop simulation studies designed to assist the USCG in the design and evaluation of systems of aids to navigation in restricted waterways. Previous experiments have examined various arrangements of aids while treating the aids themselves as fixed, rather than floating, objects. The present experiment evaluated the effects on performance of buoy excursions from their assigned positions.

The distance of buoy excursion had non-significant, but systematic, effects on waterway performance and risk. The direction of current and buoy excursion had major effects on shiphandling, waterway performance, and risk. The report contains interim guidelines to allow the application of the findings to the procedures in the SRA Systems Design Manual.

17. Key Words Short range aids to navigation visual piloting, marine simulation, piloted controllability, restricted waterways, buoy positioning, accuracy classification, buoy station dimension		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif (of this report) UNCLASSIFIED	20. Security Classif (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

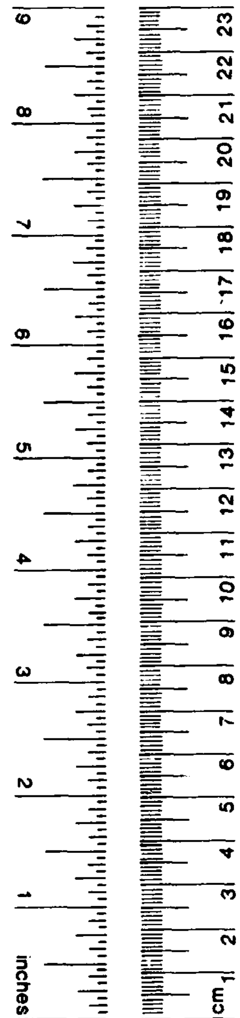
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

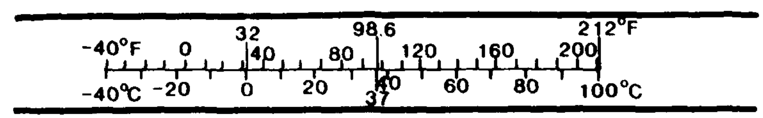
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

THE WATERWAY PERFORMANCE DESIGN AND EVALUATION PROBLEM

The United States Coast Guard's Aids to Navigation Manual - Positioning is based on the assumption that the positioning of an aid affects the degree of service provided to the mariner. That manual presents the waterway system manager with procedures to evaluate the effects of possible error in placement of an aid and possible displacement of a floating aid by current, thereby quantifying the degree of service. At the same time, the Short Range Aids to Navigation Systems Design Manual for Restricted Waterways presents procedures for the design and evaluation of aid systems based on simulator performance data collected with the aids at an exact, fixed position at the channel edge. For waterways where aids are not at the channel edge, because the bottom does not allow such placement, because the surround does not allow such precise fixes, or because current causes substantial movement of a floating aid around its mooring; the Systems Design Manual may not provide an accurate evaluation of system performance.

THE POSITIONING EXPERIMENT

The objective of the present experiment was to evaluate the effect of floating aids on waterway system performance. Selected aid arrangements from the earlier experiments were re-evaluated to establish a new baseline with fixed aid positions. Then those arrangements were evaluated with buoys displaced from the channel edge by current to a uniform distance and direction within a scenario. It was the pilot's problem to estimate the location of the dredged channel from the displaced buoys and to keep the ship on the intended track despite the displacement.

The effect of distance of displacement was evaluated by changing the distance for different scenarios. Distances were selected to represent "accuracy classifications" as defined by the Positioning Manual. Accuracy Classification A was represented by a buoy displacement from an assigned position at the channel edge of 72 feet (with a channel width of 500 feet). Accuracy Classification B was represented by a displacement of 120 feet. Accuracy Classification C was represented by a displacement of 180 feet.

The effect of direction of displacement was evaluated by changing the direction of the current for different scenarios. Four variations were created in a two-segment channel by orienting the current to each segment, in each direction. (A diagram is provided in Section 2.2.3.) Because changes in current direction affect the ship as well as the buoys, these changes had effects on the shiphandling task as well as on the position information provided by the buoys.

THE MARITIME TRAINING AND RESEARCH CENTER (MTRC)

The present experiment was done at the Maritime Training and Research Center (MTRC) in Toledo, Ohio. This simulator was developed by Ship Analytics for the Marine Engineers Beneficial Association, District 2, and is operated jointly by the union and the company.

The MTRC simulator is based on the USCG/SA prototype on which the earlier experiments were done. It is more elaborate and more advanced than the earlier simulator. For the present purposes it has a rear screen, a more complex visual scene, and more sophisticated and realistic ship hydrodynamics models.

THE RESEARCH METHODOLOGY

The research approach in the Waterway Study has been to retain the general methodology from experiment to experiment, so that comparisons of scenario performance could be made between experiments, as well as within an experiment. This experiment differed from those in the earlier phase in the simulator, in the ship model, and the pilot group. Scenarios matching those in earlier experiments on all factors possible were included to allow the evaluation of the effects of unavoidable differences on measured performance. Generally, overall performance was poorer, or risk higher, in this experiment than in those of the earlier phase. This difference is attributed largely to the MTRC 30,000 deadweight ton tanker, modeled fully loaded rather than in ballast as in the earlier phase. The Targets of Opportunity Experiment, also done at MTRC during the present phase, showed similar overall performance to the Positioning experiment.

For the present experiment, eight pilots, licensed as U.S. Registered Pilots by the U.S. Coast Guard, transited each of nine scenarios. The primary performance data were the mean and standard deviation of the crosstrack distribution of their transits through the channel. Differences in buoy excursion conditions are reflected in the precision of the tracks.

EXPERIMENTAL RESULTS AND GUIDELINES FOR APPLICATION

Floating, rather than fixed, aids did result in a deterioration of measured system performance. The mean of the set of ship tracks tended to move with the displacement of the aids, and the standard deviation tended to increase as there was less consistency among pilots as to track. The performance index used in the Systems Design Manual, the relative risk factor (RRF), was calculated to describe experimental performance. This index uses the observed mean and standard deviation of the set of ship tracks, the ship's length and beam and aspect in the channel, and the channel width to calculate the probability that there will be a "grounding" for the conditions observed. This index sometimes showed substantial increases in risk with floating aids, as the mean and standard deviation increased. When the current causing the buoy displacement acted on the ship to require a continuous crab angle, the increased effective width of the ship also contributed to risk.

This report concludes that floating aids do decrease performance, or increase risk, compared to fixed aids. For the general-purpose design and evaluation procedures of the Systems Design Manual, this difference has little consequence. The pool of performance data on which the Manual is based was collected on the simulator with relatively difficult shiphandling conditions. This research approach built in a margin of safety for low frequency or unexpected difficulties at sea. Evaluations done with the

Manual are not overly optimistic for general application to at-sea conditions. This report provides a secondary, special purpose analysis for use when buoy position and/or current is a special concern.

The distance of buoy displacement contributed to the extent of deterioration of performance. The pilots were able to compensate for some proportion, but not for all of the distance that buoys were displaced. Instructions are presented in this report for adjusting Systems Design Manual performance data to reflect the amount of displacement in ship track observed in this experiment, and to appropriately increase the measured risk.

The direction of buoy displacements had major effects on system performance. Major effects were to be expected because the current displacing the buoys also affected the ship and caused differences in shiphandling difficulty. Over the variety of conditions evaluated, there were differences in the mean of ship tracks, the standard deviation, and the effective ship width caused by the necessary crab angle. Under some conditions, the direction of current and buoy displacement was favorable to the required maneuvers, resulting in performance being better, or risk lower, than that for baseline scenarios. Instructions are presented in this report for adjusting Systems Design Manual performance data to reflect the variety of performance effects resulting from variations in the direction of current acting on buoys and ship.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Section 1

INTRODUCTION

1.1 THE POSITIONING EXPERIMENT

The simulator experiments, on which the Short Range Aids to Navigation Systems Design Manual for Restricted Waterways[1] is based, treated aids as fixed (i.e., at their exact assigned positions). In an actual waterway, of course, floating aids are not fixed at their assigned positions. Rather there is possible placement error to the mooring and possible movement around the mooring due to wind and current. The present experiment will evaluate the extent to which waterway system performance is degraded by such displacements. The experiment does not deal with buoys that are "off-station"; rather, it concerns buoys displaced from their assigned positions within accepted limits.

The Aids to Navigation Manual - Positioning,[2] provides precisely defined terms, procedures, and standards for describing the positioning of a floating aid -- a buoy. The "assigned position" is the charted position. The "positioning tolerance" is allowable error in placing the mooring. The distance by which a buoy is displaced from a position directly over its mooring (the excursion) depends upon several factors (magnitude of current, wind, and wave forces, buoy characteristics, length and type of mooring chain, depth of water). The "watch circle" of a buoy defines the area in which a buoy can travel about its mooring; its size is determined by the maximum excursion. The "buoy station dimension" is the distance from assigned (charted) position within which a buoy can be expected to lie with 90 percent confidence. It is a function of the watch circle radius and the positioning tolerance of the mooring. The buoy station dimension is used to classify buoys as to the degree of service they provide to the mariner. These Accuracy Classifications are presented in Table 1, which is reproduced from the Positioning Manual.

The Aids to Navigation Manual - Positioning also states that distances perpendicular to the channel edge are critical with respect to positioning tolerance. By the same logic, it is reasonable to assume that the impact on piloting of a given buoy excursion will depend upon its relationship to the channel edge. Accordingly, the present experiment examined the effects on waterway performance of both (1) the accuracy classification (distance of displacement) of the floating aids marking a waterway, and (2) the orientation of the current relative to the channels (direction of displacement).

---

[1]Smith, M.W., K.L. Marino, and J. Multer. Short Range Aids to Navigation Systems Design Manual for Restricted Waterways. CG-D-18-85, United States Coast Guard, Washington, D.C. 20593, June 1985 (NTIS AD-A158213).

[2]United States Coast Guard. Aids to Navigation Manual - Positioning. COMMANDANT INSTRUCTION M61500.1A. U.S. Coast Guard, Washington, D.C. 20593.

TABLE 1. ACCURACY CLASSIFICATIONS OF SERVICE PROVIDED TO THE MARINER

Accuracy Classification	Tolerance
A	30 yds (27.4 m)
B	50 yds (45.7 m)
C	75 yds (68.6 m)
D	100 yds (91.4 m)
E	150 yds (137.2 m)
F	200 yds (182.9 m)
G	greater than 200 yds from AP

Where Accuracy Classification A through F would be interpreted as "within _____ yds of the buoy's Assigned Position 90% of the time."

The experiment is designed to contribute to the refinement of the risk assessment procedures and design guidelines provided in the Design Manual. The same general methodology was employed in the present study as was used in earlier experiments. Furthermore, the channel layout and basic marking schemes were retained. Thus, while the outcome of the experiment per se is meaningful without reference to previous studies or to the Manual, the results are also applicable to the material in the Manual and interpretable within that context.

1.2 THE WATERWAY PERFORMANCE, DESIGN AND EVALUATION STUDY

The Waterway Performance, Design and Evaluation Study is the third phase of a United States Coast Guard Study. The earlier phases of the study were the Aids to Navigation Systems, Design and Evaluation Study, Phases I and II.

The central principles, on which the Study is based, were established during PHASE I. Among these is the understanding that an analytical tool must be based on an empirical analysis of the navigation process. Also established during PHASE I was the feasibility of collecting performance data in a controlled manner for a given set of conditions, at sea or on the simulator.

PHASE II (1979-1982) was the major effort. The methodology of investigating component aspects of the problem and collecting data was developed. The United States Coast Guard/Ship Analytics prototype simulator was designed and built to support data collection. The experiments -- conducted both at CAORF, the Maritime Administration's Computer Aided Operations Research Facility; and on the prototype simulator -- were a broad exploration of all important variables. A draft design manual was written to provide an exploration of the possibilities of a manual format. It was during the writing of the draft manual that the relative risk factor (RRF) was selected as the principal index for quantifying the performance of an aid system. It is an inclusive index that considers the empirical

crosstrack mean and standard deviation of a set of transits, the ship size, the ship's aspect in the channel, and the channel width. The RRF is a relative assessment of the risk, or probability, that there will be a grounding under the tested condition.

The PHASE II ADDENDUM developed and refined some of the innovations of the earlier phases. The simulator experiments -- done, again, at CAORF and on the USCG/SA simulator -- were special purpose rather than broad. The aid systems study's recommendations were supported by a validation of the USCG/SA simulator and a trial implementation at sea of the draft manual. The current Design Manual was written, benefiting from the later work and from experience with the draft manual. The Design Manual contains a review of the earlier work.

This phase will continue the development and refinement of earlier work and will extend into new areas. The planned experiments are largely special purpose. The first was the Targets of Opportunity[3] experiment. This report describes the second of these experiments. The effects of signal noise on piloting with Radio Aids will be evaluated. A new analysis of the risk contributed by Ship Performance will be developed. The major objective of the new work is the Revision of the Design Manual to incorporate new findings.

1.3 THE MARITIME TRAINING AND RESEARCH CENTER (MTRC)

The Positioning experiment was performed at the Shiphandling Simulator Facility located at the Maritime Training and Research Center (MTRC) in Toledo, Ohio. This facility was designed and built by Ship Analytics Inc., for the Marine Engineers Beneficial Association (MEBA) and is operated jointly by the union and the company. The simulator was designed with a full spectrum of capabilities to support both operational research and training, and with the flexibility and expandability to support a variety of future requirements. Its capability to simulate the marine environment for the mariner has been supported by the successful development and implementation of a variety of training and research programs. Its capability to simulate the marine environment for the mariner has also been supported by the validation of the simulator developed for the United States Coast Guard's Aids to Navigation Systems, Design and Evaluation Study, PHASE II; since the same techniques are used at MTRC for scene generation, hydrodynamics, data collection, and a variety of other functions. The simulator is described in Appendix A.

[3] Brown, W.S., M.W. Smith, and K.G. Forstmeier. Targets of Opportunity Experiment: Short Range Aids/Radio Aids Principal Findings Waterway Performance Design and Evaluation. CG-D-3-87, United States Coast Guard, Washington, D.C., March 1987.

THIS PAGE INTENTIONALLY LEFT BLANK

Section 2

THE DESIGN OF EXPERIMENT

2.1 OVERVIEW OF THE DESIGN

The experiment was designed to address a number of issues. The scenarios which provided the necessary data are summarized in Table 2. The primary aim was to investigate the effects on waterway safety of excursions of buoys from their assigned positions. Both the distance (Scenarios 3, 4, and 5) and the direction (Scenarios 4, 6, 7 and 8) of the excursion were examined. Scenarios similar to those used in previous experiments (Scenarios 1 and 2) allowed replication of and comparisons to earlier work. The scenarios are described in this section. The inclusion of a scenario (Scenario 9) with floating aids in second arrangement was meant to evaluate the generality of earlier findings.

2.2 OBJECTIVES AND EXPERIMENTAL SCENARIOS

2.2.1 Baseline Scenarios

Two of the scenarios included in the present experiment were as similar as possible to scenarios used during Phase II of the Aids to Navigation Systems series of experiments. These same two scenarios were employed in the first experiment, Targets of Opportunity, of this latest series. A system of aids with gated aids in the reaches and three aids in the turn, which was associated with good performance in the earlier experiments, serve in the present study as a baseline to which to compare other conditions. A lower-density system with staggered aids in the reaches and one aid in the turn, associated with poorer performance in previous work, provides another point on the continuum of performance. Aid arrangements for these scenarios are illustrated in Appendix B. These two scenarios are designated 1 and 2, respectively, just as they were in the prior experiment. The conditions associated with each are summarized in Table 2. These scenarios differ from others in this experiment in that, as in all earlier experiments, aids are treated as if they were fixed structures (i.e., at their assigned positions and not affected by current or wind).

2.2.2 Accuracy Classification (Distance) - Scenarios 3, 4, 5

The effect of the accuracy classification of buoys on waterway safety was assessed by varying the distance of displacement of the buoys marking the waterway. In three separate scenarios, designated 3, 4, and 5 in Table 2, all of the buoys were displaced by a distance chosen to represent an Accuracy Classification of A, B, or C (72, 120, or 180 feet, respectively). The relative displacements are illustrated in Figure 1 for the critical turn region. The direction of the displacement was determined by the current, which was uniform throughout the waterway and of the same magnitude in all three scenarios. The arrangement of aids in these three scenarios was the same as that in Scenario 1, 3-aid turn, gated aids.

TABLE 2. EXPERIMENTAL SCENARIOS

Scenario	Accuracy Classification	Current Direction	Current Speed	Aid Arrangement
Objective: Familiarization				
0	assigned position	341°T	decreasing	3-aid turn, gated aids, land, objects
Objective: Inclusion of Baseline Conditions (Fixed Aids/Decreasing Current)				
1	assigned position	341°T	decreasing	3-aid turn, gated aids
2	assigned position	341°T	decreasing	1-aid turn, staggered aids
Objective: Evaluation of Accuracy Classification (Distance)				
3	A (72 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
4	B (120 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
5	C (180 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
Objective: Evaluation of Channel/Current Orientation (Direction)				
6	B (120 feet)	161°T	0.90 knots	3-buoy turn, gated buoys
7	B (120 feet)	306°T	0.90 knots	3-buoy turn, gated buoys
8	B (120 feet)	126°T	0.90 knots	3-buoy turn, gated buoys
Objective: Evaluation of Aid Arrangements for Environment				
9	B (120 feet)	341°T	0.90 knots	1-buoy turn, staggered buoys

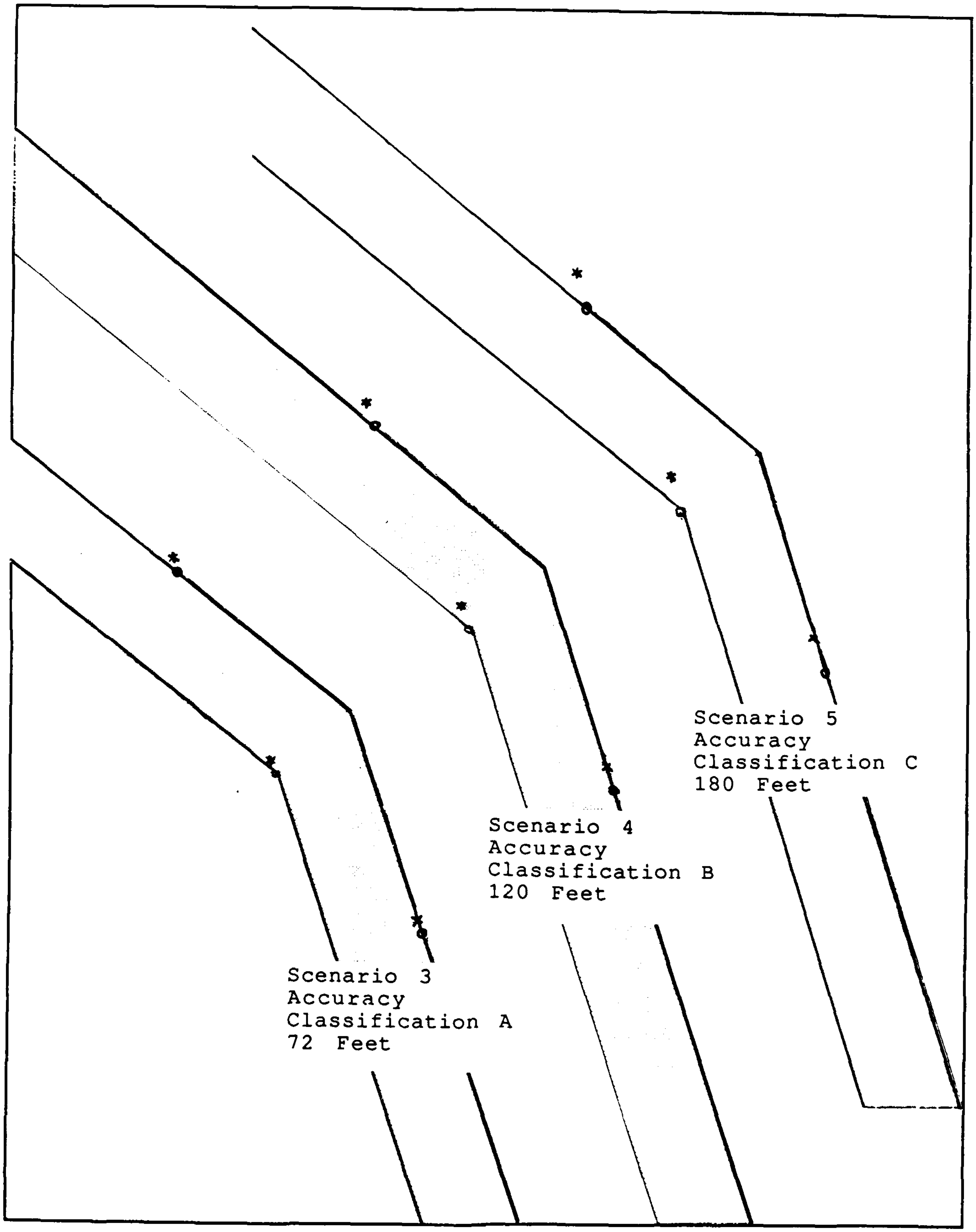


Figure 1: Buoy Displacements Representing Accuracy Classifications

The current employed in the present experiment represents a departure from the environmental conditions used in previous work, which included a decreasing current. The use of a current with a constant magnitude is necessary since current is the presumed primary cause of the displacements of the buoys. If a diminishing current were used, displacements of buoys in the second leg would likely not be distinguishable between scenarios, rendering this part of the transit uninformative. Alternatively, if buoy displacements were maintained as current diminished, scenarios might be regarded by the participants as implausible.

2.2.3 Channel/Current Orientation (Direction) - Scenarios 4, 6, 7, 8

There are logically an infinite number of possible channel/current orientations. However, in reality, it is most often the case that many sections of a waterway are roughly parallel to the direction of the current. Thus, four orientations of the current were examined in four separate scenarios (designated 4, 6, 7, 8 in Table 2). The current was oriented parallel to the first or second leg of the waterway, either following ownship or in a reciprocal direction in that leg. The effects of displacement of the turn buoys by these currents are illustrated in Figure 2. The current has the effect of shifting the apparent position of the leg that it crosses. In the scenarios, buoys were displaced in the corresponding direction by an amount chosen to represent Accuracy Classification B (120 feet).

2.2.4 Floating Aids - Staggered Arrangement (Scenario 9)

The effects of displacement distance and direction were examined using the gated buoy arrangement in most of the experimental scenarios. Although it was not feasible to duplicate these manipulations for a second, staggered buoy arrangement, it was of interest to determine whether gated and staggered arrangements were differently affected by displacement. Scenario 9 consisted of the staggered arrangement with aids displaced by 120 feet.

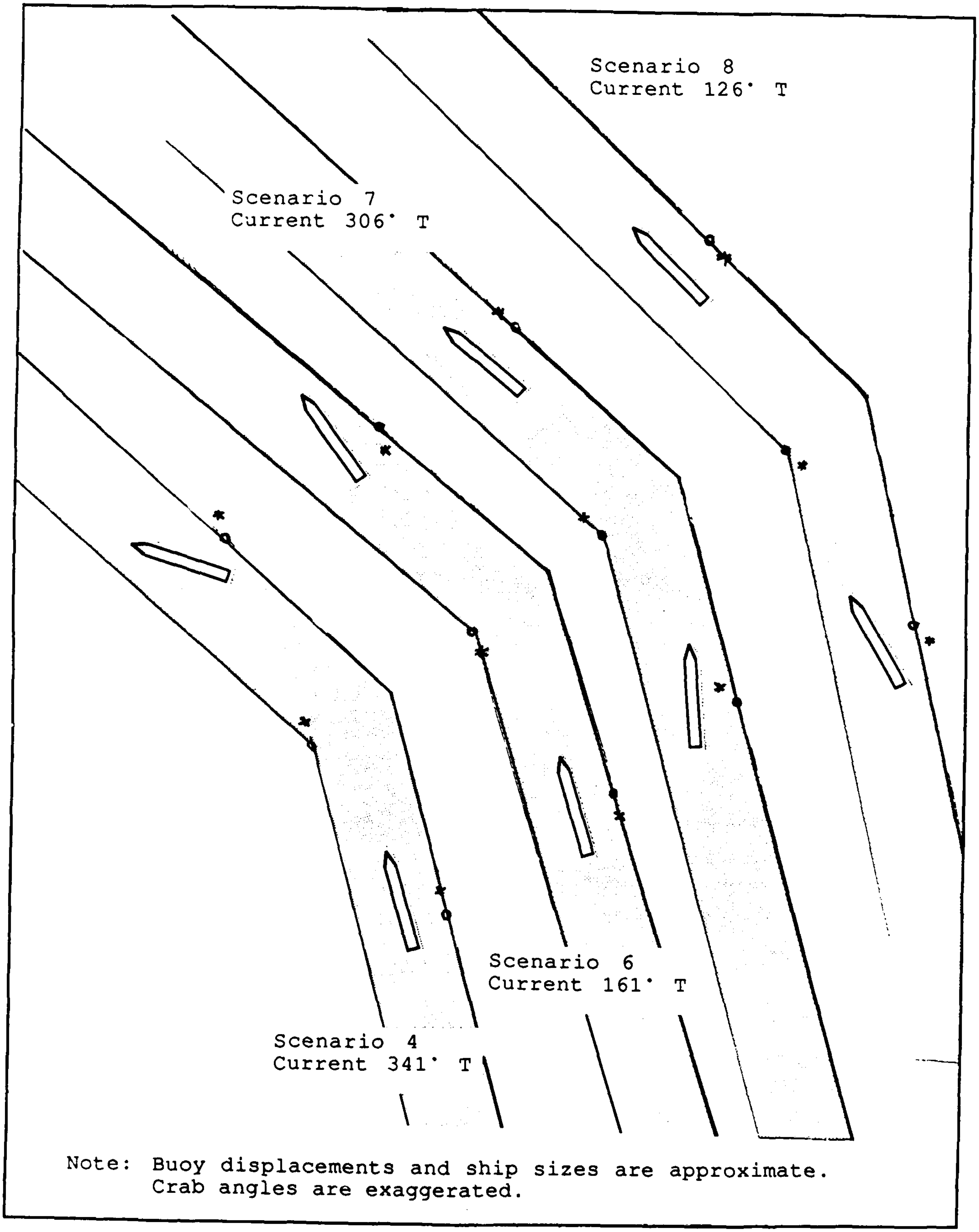


Figure 2: Buoy Displacements Representing Channel/Current Orientation

THIS PAGE INTENTIONALLY LEFT BLANK

Section 3

SIMULATION METHODOLOGY

3.1 SIMULATED WATERWAY, WIND AND CURRENT

The basic channel configuration, is the same for all scenarios, is illustrated in Figure 3. It consisted of two legs connected by a 35-degree turn to port. For Scenarios 1 and 2 the current varied just as it did in the previous (TOO) experiment. In Leg 1 there was a following current which decreased in magnitude from 1.3 knots at the start of the transit to approximately 1.0 knots at the turn point. In Leg 2, the current was from the vessel's port quarter and continued to decrease in magnitude, reaching zero knots by the end of the transit. In each of the other scenarios, Scenarios 3-9, the current was of uniform magnitude and direction throughout the waterway. The current differed in direction from one scenario to the next, as described in Table 2 in Section 2. The wind direction was from an approximate reciprocal bearing to the current direction in each scenario, nifying its effect. Wind speed was gusting to 30 knots. The conditions for each scenario are described in Appendix B, as instructions to the pilot.

3.2 SHIP MODEL

The ship hydrodynamic model used was a 30,000 deadweight ton (dwt) tanker ailable at MTRC. It is 595 feet long between perpendiculars, 85 feet in eam, with a draft of 34.6 feet. It is modeled fully loaded. It has a plit house with the eye location in the bridge 85 feet forward of the enter of gravity and 47.5 feet above the water. The engine order elegraph-to-speed table and turning circles appear in the instructions to e pilot in Appendix B.

3.3 SHIPHANDLING TASK

The general approach for the simulator data collection was to design a shiphandling task and to keep it constant across scenarios while conditions change with the experimental variables. The baseline shiphandling task was carried over from the experiments of Phase II, to facilitate the comparison of performance data across phases. The scenario events and the performance requirements are illustrated in Figure 3 for Scenario 1. This figure is taken from the "Instructions to Pilot" in Appendix B. It is accompanied there by a discussion for the pilot's use. The experimental design of the present experiment required changes in wind and current conditions from the baseline scenario events. Differences among scenarios, necessary for the experimental variables, are described in Section 2, Table 2 and in Appendix B.

The baseline task carried over from earlier experiments was designed to sample a variety of performance requirements: 1) recovery to the centerline with following wind and current, 2) trackkeeping with following wind and current, 3) a turn maneuver, 4) recovery to the centerline with a crosstrack wind and current, and 5) trackkeeping with a crosstrack and current. The

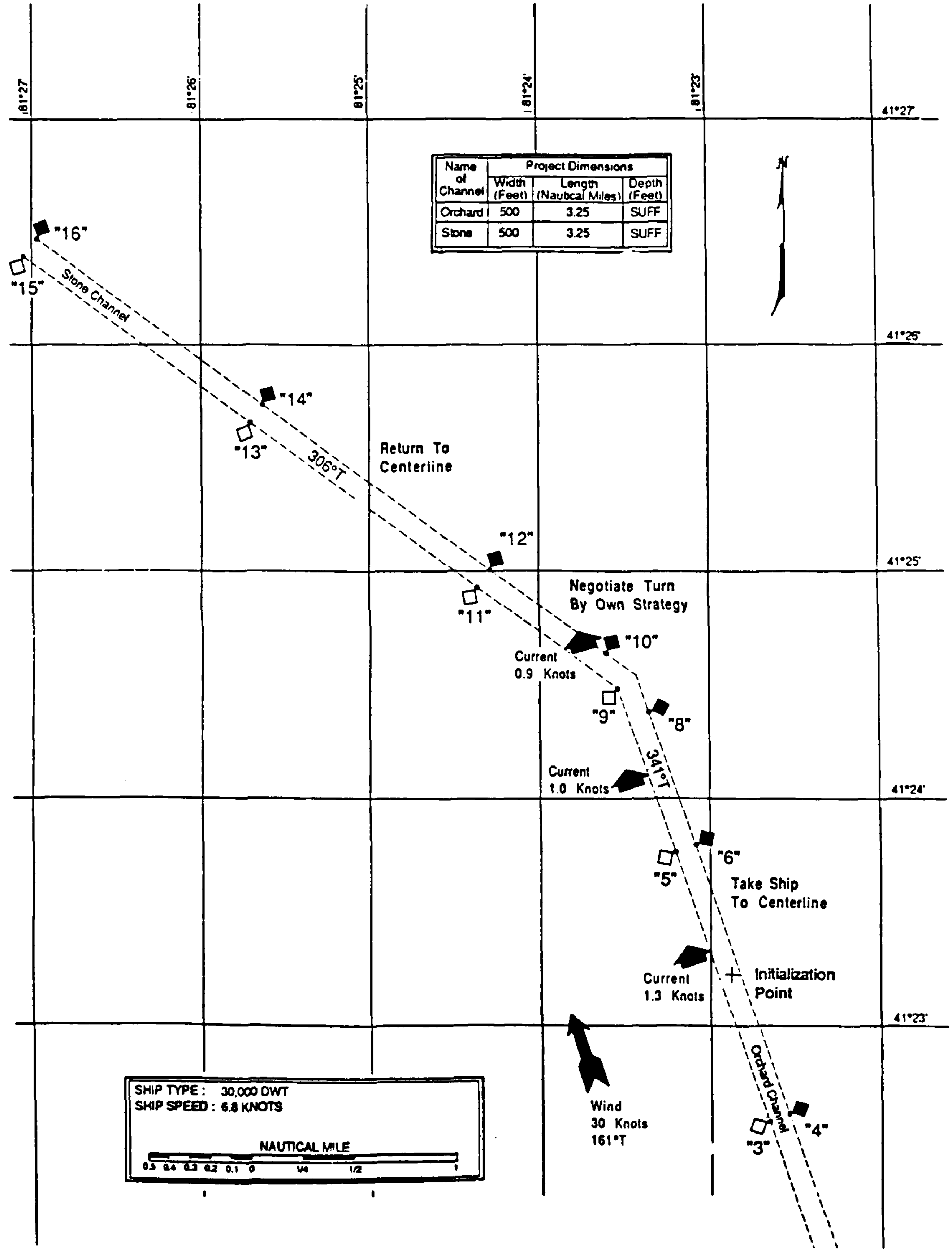


Figure 3: Scenario Events and Performance Requirements (Scenario 1 as an Example).

Leg 1 requirements with following wind and current are relatively easy. The 35° noncut-off turn is relatively difficult for a commercial, deep-draft vessel. In addition, the experimental wind and current magnify the difficulty, combining with the turn forces to push the ship out of the channel. The wind, current, and slow ship speed mean the recovery to the centerline must be accomplished with the appropriate crab angle to hold the ship against the current. Trackkeeping requires constant adjustment of the ship's head as the current decreases and the wind gusts. Generally, the mean of a set of tracks does not achieve the centerline until the crosstrack current decreases to zero.

The performance requirement of achieving the centerline under relatively difficult condition serves the objective of discriminating among the conditions selected for evaluation in an experiment. Typically, the precise shiphandling possible in Leg 1 does not discriminate among conditions, contributing little to experimental objectives. The more difficult requirements in Leg 2 force the pilot to depend more heavily on the available aid information for ship control. Consequently, Leg 2 performance is generally more sensitive to differences among experimental conditions. The requirement of achieving the channel centerline contributes to the general difficulty and to the sensitivity to differences. Giving the pilots a common trackline also serves to decrease the variability within a scenario and makes it possible to do statistical tests between scenarios. The centerline track is not unrealistic for a deep-draft ship in a narrow channel with no oncoming traffic. Such behavior was observed at sea under similar conditions. An sample of at-sea data, appearing in this report in Section 6 in Figure 7, supports the realism of a centerline track.

3.4 PILOTS

Eight test subjects were required for the experiment. All were licensed as U.S. Registered Pilots by the U.S. Coast Guard. All had also attained the following licenses or endorsements.

- First Class Pilot's license for Duluth, Gary, Buffalo, and all rivers
- U.S. Coast Guard Certified Radar Observer

Pilots who participated in the experiment actively pilot ocean-going vessels, as large as 30,000 dwt and 600 feet in length, entering the Great Lakes. All pilots were required to have recent experience piloting ships in restricted waterways comparable to those that will be simulated in the experiment. One pilot with previous experience at the MTRC simulator participated in trial runs prior to the start of formal data collection. Based upon consultation with the pilot, procedures and scenario particulars were modified. The remaining pilots were chosen without regard to their having had experience at MTRC or any other simulation facility. Five of the pilots had participated in the Targets-of-Opportunity study, three had no prior experience at MTRC.

3.5 PROCEDURES

Each pilot's day consisted of the following events.

1. The briefing was based on the "Instructions to the Pilot" which appears as Appendix B.

2. The familiarization run was the same as that used in the Targets of Opportunity experiment. It familiarized the pilot with the ship, channel, and most frequently occurring buoy arrangement. It included the same wind and current as in the baseline Scenarios (1 and 2). It included an additional maneuver not included in the experimental scenarios to increase the pilot's familiarity with the maneuvering performance of the ship: an approach and turn on to the channel. It is illustrated in Appendix B.

3. The experimental scenarios were run in a different random order for each subject. This arrangement minimizes carry-over effects which can result from one scenario repeatedly following another. It also prevents bias that can result from presenting a particular scenario consistently at the same position in the order (e.g., early in the day when the pilot is less familiar with the ship, or late in the day when he may be fatigued). The content of the scenarios are described in Appendix B.

4. Subjective data were collected from the pilots during discussions guided by the questionnaire attached as Appendix C. The discussions were conducted throughout the day as opportunity and issues presented themselves.

Section 4

SIMULATION DATA AND PERFORMANCE MEASURES

4.1 SIMULATOR DATA COLLECTION

During the simulation a variety of data were recorded for potential later examination and analysis. They were as follows.

1. Computer-Recorded Measures. As the "ship" transited the channel, its crosstrack position was recorded as a function of along track position. These measures form the primary data of the experiment. Their use is described in the following subsections. The computer also recorded other ship status measures, including: speed, yaw rate, heading, course, rudder angle, and engine revolutions per minute.

2. Operator-Entered Measures. The pilot's helm orders -- course, rudder, and engine order telegraph -- were entered at the terminal by the simulator operator. These orders were recorded by the computer along with measures of ship's position and status.

3. Pilot's Subjective Reactions. The pilot's comments and reactions to all aspects of the simulation were noted by the researcher. The questionnaire that was used to guide the discussions appears as Appendix C.

4.2 SUMMARY OF SCENARIO PERFORMANCE

After the simulation phase of the experiment, the ship position measures were accessed and subjected to a number of off-line calculations and plots. A sample of a "combined" plot appears on page D-3. First, at "data lines" placed at 475-foot intervals along a channel, the performance for the eight transits of each scenario was summarized by calculating the mean and standard deviation of the crosstrack position of ownship's center of gravity. The mean is expressed as feet from the centerline of the dredged channel. Positive values are to the right (starboard as the ship transits the channel). The placement of the data lines is indicated by the tick marks along the channel edge. The performance in a scenario is described by plotting the crosstrack mean and standard deviation as a function of along track distance, or data line. Such plots are illustrated by the top two axes in on page D-3. The mean and standard deviation is combined to provide a graphic envelope of expected performance within the channel boundaries. The "envelope" on the third axis on page D-3 is formed by the mean with two standard deviations to either side. The envelope represents 95 percent of expected transits for the tested conditions.

A second type of combined plot is illustrated by page D-4. This shows the same envelope through the 35-degree turn. Tick marks along the channel edge indicated the same data lines as in the straight axis plots. Note that this second combined plot shows only the turn, magnified to present a more effective graphical presentation of performances in this critical region.

4.3 COMPARISONS BETWEEN SCENARIOS

A "comparison" plot is illustrated on page E-3. The means and standard deviations from two different scenarios are plotted on the same axes. Such comparisons are made more meaningful with statistical tests. The means were compared using a t-test; the standard deviations were compared as variances, using an F-test. These are both frequently used tests. One description of them appears in McNemar.[4] In comparison plots the arrows along the abscissa indicate statistically significant differences at the 0.10 level at the corresponding data lines.

Statistical significance at the 0.10 level means that a difference as large as that observed between two conditions can be expected by chance with a probability of 0.10 or less. Therefore, it is likely that the hypothesized mechanism (for example, accuracy classification) is responsible for the observed difference. If statistical significance is not present, the differences observed could have occurred by chance.

4.4 THE RELATIVE RISK FACTOR (RRF) ON SELECTED POINTS

The Design Manual makes use of an index, the relative risk factor (RRF). This index takes into consideration the mean and standard deviation of vessel tracklines, ship dimensions, ship aspect, and channel width to produce a number which is proportional to the probability of grounding for the simulated conditions. The RRF is operationally defined by the sample calculation in Table 3 which is taken from the Design Manual, Section 2. That report contains an extensive discussion of that index.

The index is not reported for each data line. Rather, values were selected to represent each of five regions in the channel. In order of occurrence in the transit, the regions were 1) recovery to centerline, 2) trackkeeping, 3) turn pullout, 4) recovery to centerline with a second current condition, and 5) trackkeeping on the centerline with a second current condition. A value was selected as characteristic of the ship maneuver being performed in the region.

- For a turn region a value was selected in the turn pullout at the point in the transit were the crosstrack acceleration toward the outside edge of the channel approximates zero. Presumably, this point is the maximum risk of grounding; from that point the mean generally starts back to the channel centerline. Generally, this is Data Line 3, approximately two ship lengths past the turn apex.

- For a recovery region a value was selected where the mean shows a large crosstrack velocity and the standard deviation is high. If several data lines appeared appropriate, the one with the highest RRF was selected.

---

[4]McNemar, Q. Psychological Statistics. Fourth Edition, Wiley, New York, 1969.

TABLE 3. SAMPLE CALCULATION OF RELATIVE RISK FACTOR (RRF) IN THE RECOVERY REGION*

SHIP PARAMETERS

Ship size	30,000 deadweight tons
Ship length	590 feet
Ship beam	85 feet
Crosstrack current velocity	0.25 knots
Transit speed	6 knots
B' (feet)	54.79 feet

CHANNEL PARAMETERS

Channel width	500 feet

SAMPLE CALCULATION OF RRF: Crab angle, 2-5 degrees; gated aids; day

[W/2) - (MN) - (B')]/(SD) = (NS)	reminder:
[(500/2) - (97) - (54.79)]/(34) = (2.89)	W: channel width
	MN: mean
	B': adjusted beam/2
[(W/2) + (MN) - (B')]/(SD) = (NP)	SD: standard deviation
[(500/2) + (97) - (54.79)]/(34) = (8.59)	NS: SDs to starboard
	NP: SDs to port
	PS: prob to starboard
(PS) + (PP) = (RRF)	PP: prob to port
(0.0019) + (0.0000) = (0.0019)	RRF: relative risk factor

* This table is taken from the SRA Design Manual, Page 2-17 and shows the standard ship dimensions used there.

- For a <u>trackkeeping region</u> a value was selected where the mean and standard deviation approximate a constant level or "steady state". With a substantial crosscurrent or with staggered buoys, trackkeeping may not be substantially lower in RRF than the recovery region.

4.5 THE RELATIVE RISK FACTOR FOR THE WATERWAY (RRFW)

It is useful both for experimental and practical purposes to be able to characterize the performance of an arrangement of aids to navigation throughout a waterway by a single number or index. The Relative Risk Factor for a Waterway (RRFW) is calculated from the RRFs for the regions comprising the waterway. The concept comes from system engineering where the reliability of a system is taken to be the product of the reliabilities of system components. Since the RRF is assumed to be proportional to the probability of grounding in a region; that is, component failure; (1-RRF) is used to represent the "reliability" of each "component". The product of the (1-RRF) for n regions is (1-RRFW).

$$(1-RRFW) = (1-RRF1)(1-RRF2) \ldots (1-RRFn)$$

Note that, like the regional RRF value, RRFW is a relative measure of performance.

Section 5

EXPERIMENTAL RESULTS

5.1 INTRODUCTION

The effects of fixed versus floating aids, aid displacement distance, channel/current orientation, and aid arrangement were evaluated by comparing piloting performance in scenarios that represent different levels of each experimental variable. The characteristics of the experimental scenarios are summarized in Table 4. The scenarios are further described by the instructions and chartlets in Appendix B. Performance in each scenario is presented as a combined plot in Appendix D. Comparisons between scenarios corresponding to the effects of interest are summarized in Table 5 and described below. Each comparison is supported by a comparison plot contained in Appendix E.

5.2 FIXED AIDS VERSUS FLOATING AIDS

The experimental variables to be evaluated in this experiment necessitated a change from the scenario conditions and the resulting shiphandling requirements of the earlier experiments. Scenarios 1 and 2 reproduce earlier conditions. In earlier experiments aids were fixed at their exact assigned positions. Some variety and difficulty was added to shiphandling with current (and wind) that followed in Leg 1 (341°T) and came from the port quarter after a turn to port. To ensure constantly changing conditions, that would require the pilots to depend on the aids; the current decreased throughout the scenarios, requiring a continuous adjustment of crab angle. In the present experiment the buoys in Scenarios 3 to 9 were displaced from their assigned positions. Since buoys are displaced primarily by current, current had to be changed from the earlier condition to create a variety of believable conditions.

5.2.1 Comparison of Fixed Versus Floating Aids: Scenarios 1 and 4

The difference between earlier and present shiphandling conditions can be evaluated by a comparison of Scenarios 1 and 4. Scenario 1 has fixed aids and a decreasing current. Scenario 4 has a current to the same 341°T and buoys displaced by a constant current. The current in the latter scenario is constant rather than decreasing: if the current had decreased, the buoys would have to return to their assigned positions and the second leg would be less informative. The two scenarios were planned so that the current was the same 0.9 knots from 341°T at the critical turn pullout. This is the only point in the experiment where fixed and floating aids can be compared with the same current velocity (set and drift), affecting the ship. The results of this comparison may be found in Table 6. Note that performance in Leg 1 was similar under both experimental conditions. The displacement of the buoys in Leg 1 with the following current had no measurable effect. At the turn pullout, there was a difference in mean and standard deviation which, though not statistically significant, resulted in a doubling of RRF. Since the current is the same at this point, performance difference must be attributable to buoy position. In Scenario 4 the buoys are late and to the outside.

TABLE 4. EXPERIMENTAL SCENARIOS

Scenario	Accuracy Classification	Current Direction	Current Speed	Aid Arrangement
Objective: Familiarization				
0	assigned position	341°T	decreasing	3-aid turn, gated aids, land, objects
Objective: Inclusion of Baseline Conditions (Fixed Aids/Decreasing Current)				
1	assigned position	341°T	decreasing	3-aid turn, gated aids
2	assigned position	341°T	decreasing	1-aid turn, staggered aids
Objective: Evaluation of Accuracy Classification (Distance)				
3	A (72 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
4	B (120 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
5	C (180 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
Objective: Evaluation of Channel/Current Orientation (Direction)				
6	B (120 feet)	161°T	0.90 knots	3-buoy turn, gated buoys
7	B (120 feet)	306°T	0.90 knots	3-buoy turn, gated buoys
8	B (120 feet)	126°T	0.90 knots	3-buoy turn, gated buoys
Objective: Evaluation of Aid Arrangements for Environment				
9	B (120 feet)	341°T	0.90 knots	1-buoy turn, staggered buoys

TABLE 5. COMPARISONS REPRESENTING EXPERIMENTAL EFFECTS

EFFECT	SCENARIOS
Fixed Aids Versus Floating Aids	
With 3-Aid Turn/Gated Aids	1 vs 4
Accuracy Classification (Distance)	
A (72 feet) versus B (120 feet)	3 vs 4
B (120 feet) versus C (180 feet)	4 vs 5
A (72 feet) versus C (180 feet)	3 vs 5
Channel/Current Orientation (Direction)	
Crosscurrent in Turn Pullout Leg: (341°T versus 161°T)	4 vs 6
Parallel Current in Turn Pullout Leg: (306°T versus 126°T)	7 vs 8
Aid Arrangements	
Fixed Aids: 3-Aid Turn/Gated Aids versus 1-Aid Turn/Staggered Aids	1 vs 2
Floating Aids: 3-Aid Turn/Gated Aids versus 1-Aid Turn/Staggered Aids	4 vs 9

TABLE 6. COMPARISON OF FIXED AIDS/DECREASING CURRENT (SCENARIO 1) WITH FLOATING AIDS/CONSTANT CURRENT (SCENARIO 4)

	FIXED AIDS/DECREASING CURRENT (SCENARIO 1)	FLOATING AIDS/CONSTANT CURRENT (SCENARIO 4)
Leg 1 Recovery Region [1]		
MN[2]	4	4
SD[3]	40	29
(B'[4]	42.5)	42.5)
RRF[5]	0.0000	0.0000
Leg 1 Trackkeeping Region		
MN	-6	-6
SD	41	28
(B'	42.5)	42.5)
RRF	0.0000	0.0000
Turn Pullout		
MN	144	173
SD	45	62
(B'	67)	67)
RRF	0.1922	0.4364
Leg 2 Recovery Region **		
MN	114	133
SD	60	81
(B'	54.8)	67)
RRF	0.0885	0.2676
Leg 2 Trackkeeping Region * **		
MN	-6	97
SD	98	84
(B'	54.8)	67)
RRF	0.0459	0.1543
RRFW[6]	0.2975	0.6509

* Significant differences between means in this region. See Appendix E.
** Significant differences between standard deviations in this region. See Appendix E.

NOTES:
1. See Section 4.4 for a description of the selection of data for the region.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).
The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.
6. RRFW: waterway relative risk factor. See Section 4.5.

Differences continue down the second leg. In the recovery region, a difference between mean crosstrack positions was found to be significant. This difference was accompanied by an increase in the RRF for Scenario 4. In the trackkeeping region of Leg 2, both a difference in mean crosstrack position and in the standard deviation of the mean position, were found between the two scenarios. Similar to the recovery region, this difference was also accompanied by an increase in the RRF for Scenario 4. The conditions in Leg 2 differ between the two scenarios in both aid position -- buoys are displaced to the outside for Scenario 4 -- and current velocity -- current remains high for Scenario 4 -- and the contributions of these two factors cannot be separated. This is the case at sea.

5.3 ACCURACY CLASSIFICATION (DISTANCE)

The concept of "Accuracy Classification," as defined by the Aids to Navigation Manual -- Positioning, was translated into several distances of buoy displacement from an "assigned position" at the exact channel edge. Three scenarios were included in the experiment, differing only in this distance.

- Scenario 3 represented Accuracy Classification "A" with a distance of 72 feet.
- Scenario 4 represented Accuracy Classification "B" with a distance of 120 feet.
- Scenario 5 represented Accuracy Classification "C" with a distance of 180 feet.

Aid arrangement and current velocity were the same. The critical turn region is illustrated in Figure 4. The assigned position is indicated by a circle; the actual position, by an asterisk.

To approximate realistic performance, the pilots needed some information about buoy displacement. At sea they would have "local knowledge" about currents and, possibly, a view of landmass and fixed objects to help their judgment of position. To substitute for such information, the pilots were told that for a given scenario the buoys would be displaced ______ yards by the current. Their problem was to estimate the location of the dredged channel and to maneuver the ship along their preferred track in the channel, despite the bias presented by the actual position of the buoys.

5.3.1 Comparison of Accuracy Classifications A, B, C: Scenarios 3, 4, and 5

Performance in Scenarios 3, 4, and 5 is summarized in Table 7. In the first two sections of the waterway (recovery and trackkeeping without crosscurrent), RRF values were low and tracklines were apparently unrelated to the degree of buoy displacement. This was as expected, since in the first leg the displacement was alongtrack. In the second leg, where buoys were displaced crosstrack, the mean tends to follow over and the standard deviation tends to increase. The differences in average trackline among these scenarios were not statistically significant, however. RRF tends to increase with the degree of displacement.

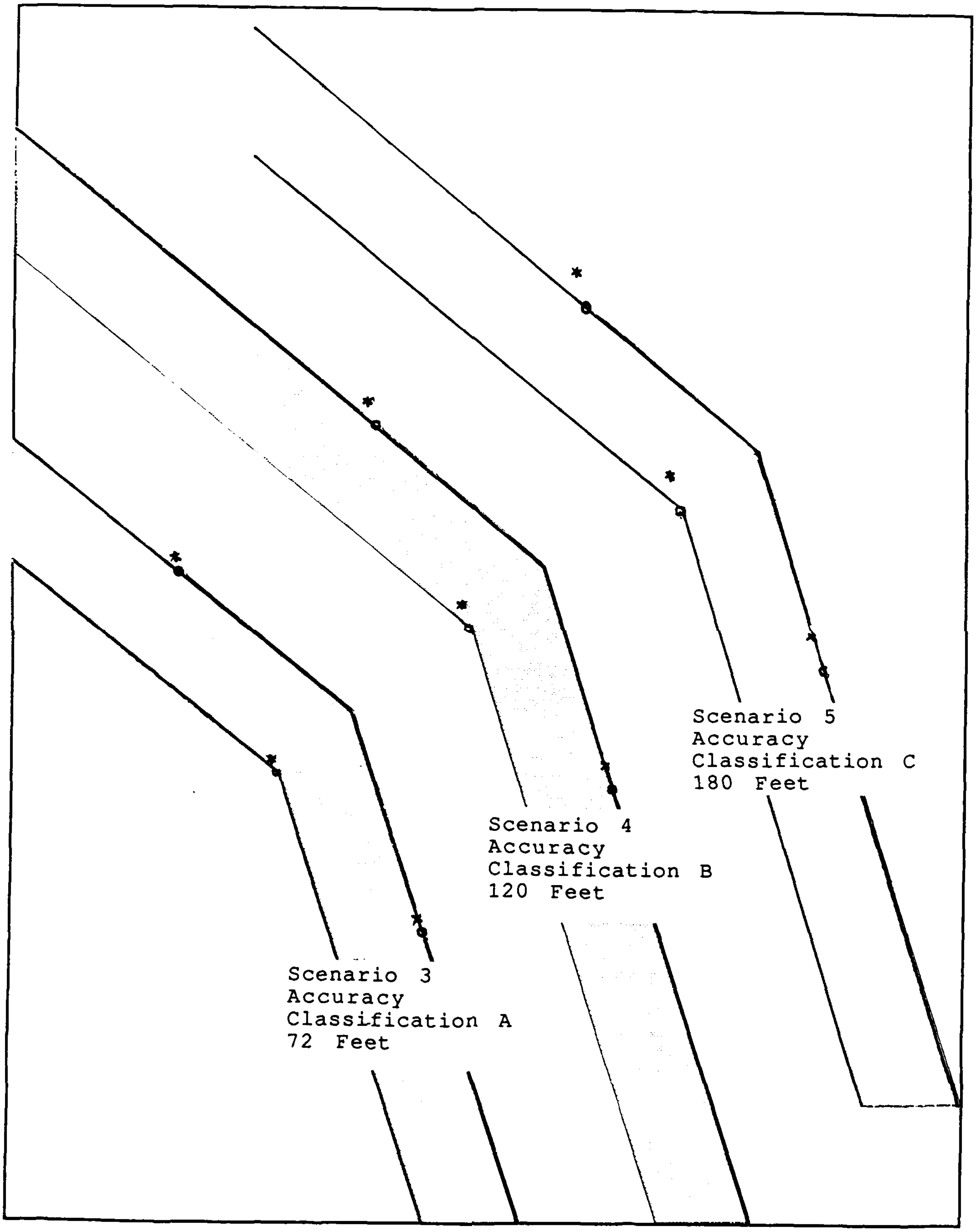


Figure 4: Buoy Displacements Representing Accuracy Classifications

TABLE 7. COMPARISON OF BUOY DISPLACEMENT DISTANCES OF 72 FEET (SCENARIO 3), 120 FEET (SCENARIO 4), AND 180 FEET (SCENARIO 5)

	ACCURACY CLASS A: 72 FEET (SCENARIO 3)	ACCURACY CLASS B: 120 FEET (SCENARIO 4)	ACCURACY CLASS C: 180 FEET (SCENARIO 5)
Leg 1 Recovery Region[1]			
MN[2]	-5	4	18
SD[3]	56	29	38
(B'[4]	42.5)	42.5)	42.5)
RRF[5]	0.0002	0.0000	0.0000
Leg 1 Trackkeeping Region			
MN	-31	-6	11
SD	48	28	37
(B'	42.5)	42.5)	42.5)
RRF	0.0001	0.0000	0.0000
Turn Pullout			
MN	177	173	196
SD	61	62	75
(B'	67)	67)	67)
RRF	0.4602	0.4364	0.5675
Leg 2 Recovery Region			
MN	139	133	149
SD	53	81	76
(B'	67)	67)	67)
RRF	0.2061	0.2676	0.3050
Leg 2 Trackkeeping Region			
MN	30	97	80
SD	81	84	84
(B'	67)	67)	67)
RRF	0.0345	0.1543	0.1101
RRFW[6]	0.5864	0.6509	0.7325

NOTES:
1. See Section 4.4 for a description of the selection of data for the region.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).
The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.
6. RRFW: waterway relative risk factor. See Section 4.5.

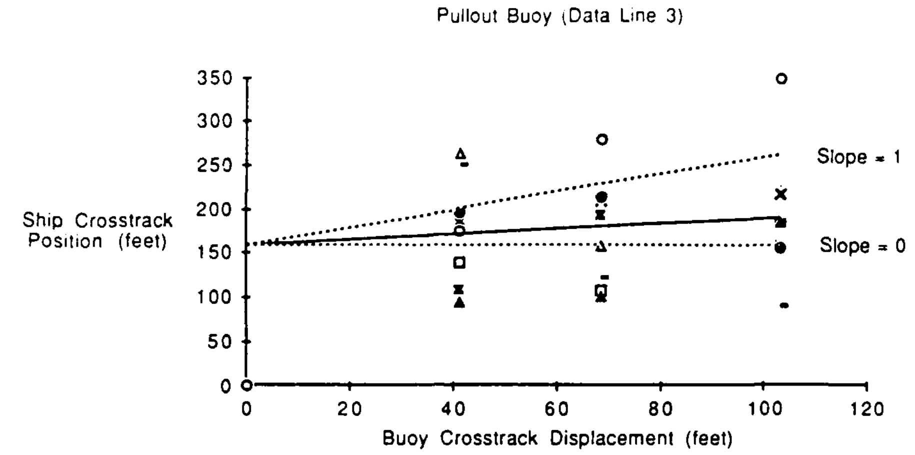
The overall effect of the displacement of the buoys on the trackline achieved by pilots in the second leg is illustrated in plots of the mean ship track position as a function of buoy position. This function is shown for three points in the second leg in Figure 5, respectively. The data were selected at the points where the ships passed the turn pullout buoy, the first gate beyond, and the second gate. This selection was based on the assumption that at these points the pilots would be most influenced by the actual position of the buoys. If pilots had compensated perfectly based on the information they were given regarding displacement, the best-fitting line would be nearly horizontal: i.e., its slope would be zero. If, on the other hand, pilots had completely disregarded the information regarding buoy displacement, the resultant function (line) would have a slope of approximately one, the top line shown. The line fitted through observed performance does show an increase with buoy displacement, but not in a one-to-one fashion. The fit is the solid line on the plot, surrounded by symbols representing individual positions. The slope of the fitted crosstrack performance shows that the pilots did, in fact, compensate for the displacement of the buoys (the slope of the line drawn through the points was less than one in every plot); but not to the point where perfect compensation occurred (the slope of the line for obtained performance did not equal zero).

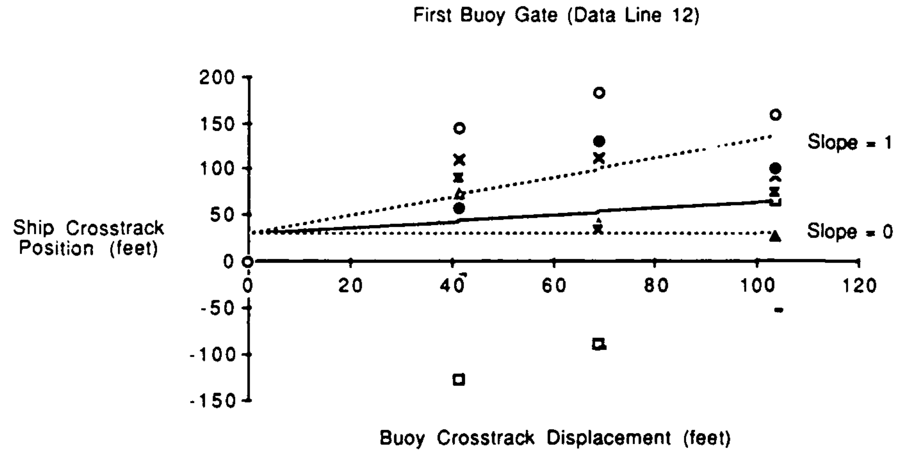
5.4 CHANNEL/CURRENT ORIENTATION (DIRECTION)

The Aids to Navigation Manual - Positioning suggests that direction, as well as distance, of displacement affects the service provided to the mariner. Four variations in direction of buoy displacement were created in the two-segment channel by orienting the current to each segment, in each direction. The conditions in Scenarios 4, 6, 7, and 8 are summarized in Table 4. The buoy displacements in the critical turn regions are illustrated in Figure 6. The assigned position of the buoy is indicated by a circle; the actual position, by an asterisk. The effects of buoy displacement and current direction combine to vary the shiphandling difficulty of the scenarios. The ship outlines are included to show the direction of crab angle needed to maintain a track in the current. The size of the ships is to scale but the crab angle is exaggerated for illustration. The aid arrangement was the same for all four scenarios; the distance of displacement was constant within and between scenarios at 120 feet; the velocity of the current was constant within and between scenarios at 0.9 knots.

Again, the pilot needed information to compensate for lack of "local knowledge" about currents and lack of visible fixed points. The pilot was told the direction of current and of buoy displacement, but he had other sources of this information. The visual scene showed a wake on the buoys in the appropriate direction and the current acted appropriately on the ship.

Each of the scenarios provides a fairly unique shiphandling problem, and could be discussed separately. Note that the very different performance resulting from these four conditions is especially well illustrated by plots of combined ship tracks through the turns provided in Appendix D. To continue the experimental convention of discussing the scenarios as comparisons, the scenarios employing reciprocal currents were paired.





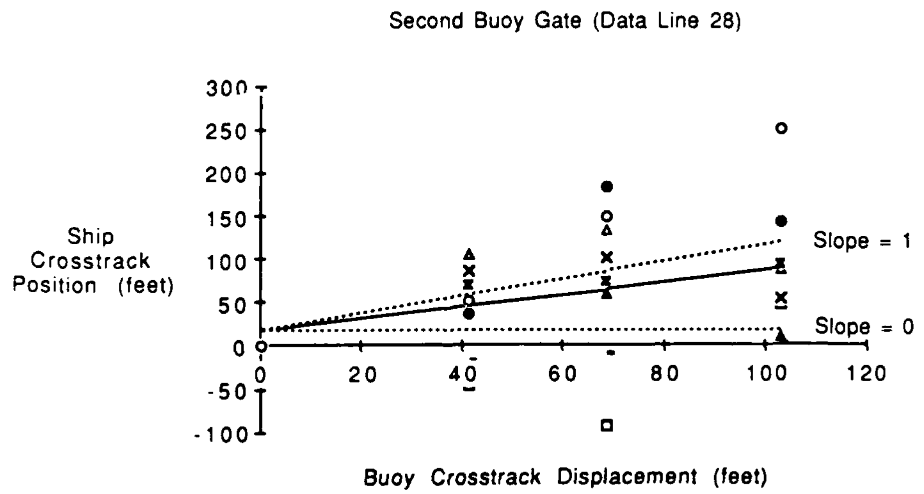


Figure 5: Ship's Crosstrack Position (Feet) as a Function of Distance of Crosstrack Buoy Displacement (Feet)

KC64

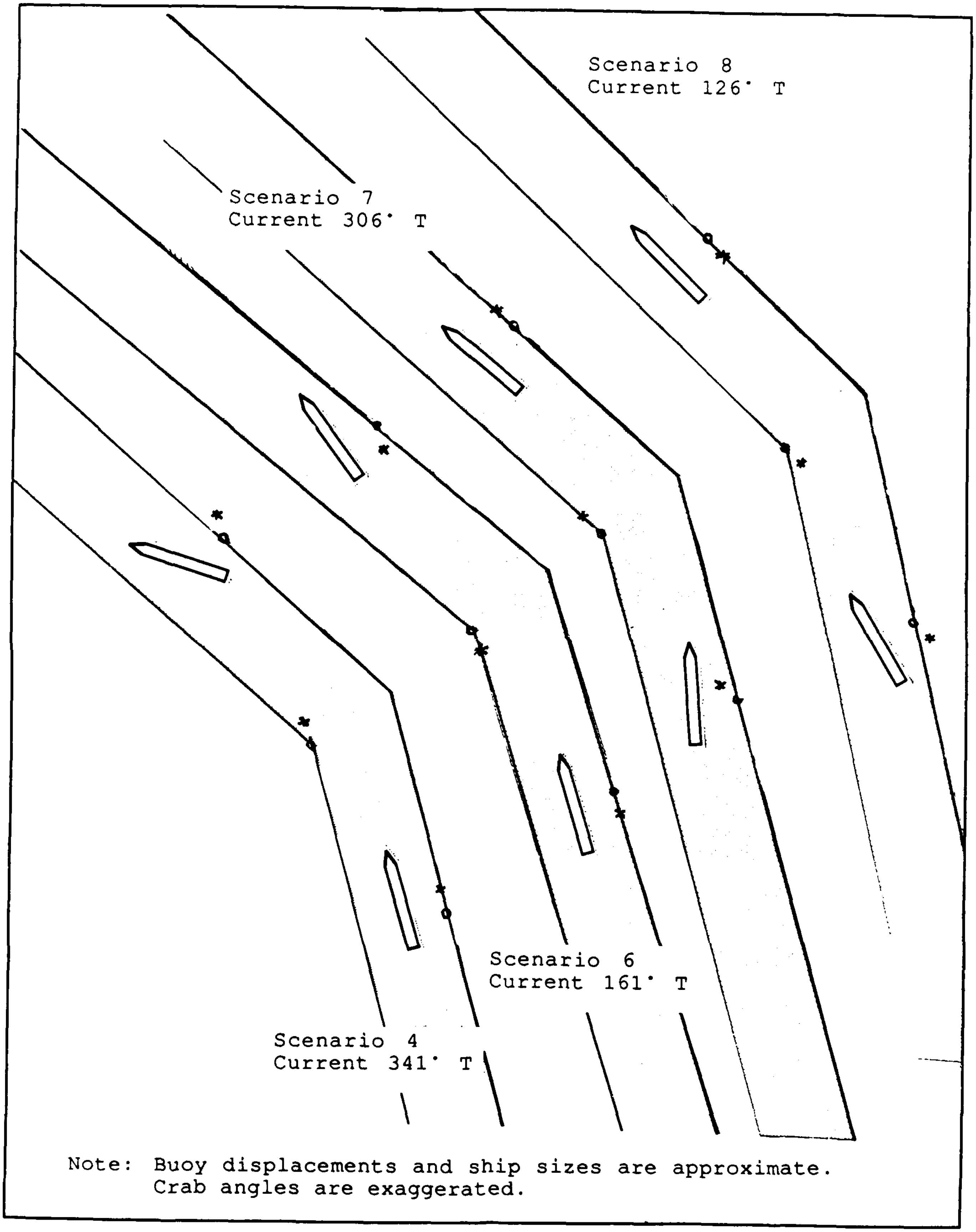


Figure 6: Buoy Displacements Representing Channel/Current Orientation

5.4.1 Crosscurrent in Turn Pullout Leg: *Scenarios 4 and 6*

Scenarios 4 and 6, with reciprocal currents of 341°T and 161°T, have a parallel current in the first leg and crosscurrent in the turn pullout leg. Scenario 4 is the "worst-case," of all the four considered. The actual positions of the buoys encourage a late start to the turn and a pullout that is to the outside; at the same time the current exaggerates turn forces, pushing the ship to the outside at the pullout and requiring a crab angle for recovery. In Scenario 6 the positions of the buoys encourage a more favorable early start to the turn and a pullout that is well to the inside of the channel edge. Current forces also act to keep the ship away from the channel edge, but still require a crab angle for recovery.

These considerable differences in conditions resulted in substantial differences in performance as summarized in Table 8. Mean distance from centerline differed significantly for all regions except trackkeeping in Leg 1. For Leg 1 trackkeeping, a significantly greater standard deviation for Scenario 6 than for Scenario 4 was found. The Scenario 6 shows a lower RRF value in the turn pullout than does Scenario 4. Both the action of the current, and displacement of the buoys appeared to maximize the likelihood of the ship approaching the starboard channel boundary after the turn in Scenario 4. In Scenario 6 the situation was just the opposite; both the current and the buoy displacement tended to keep the ship inside the channel after the turn. Performance in Scenario 4 in Leg 2 improves from turn to recovery to trackkeeping. There is no such improvement for Scenario 6. Note that the RRF values are lower for Scenario 4 in every region except the turn pullout. The higher RRF values for Scenario 6 may be the result of experimental context. There are a number of other scenarios with current directions similar to that of Scenario 4, but only Scenario 6 has a head current in Leg 1 and a current from right to left (starboard to port) after the turn.

5.4.2 Parallel Current in Turn Pullout Leg: Scenarios 7 and 8

Performance in Scenarios 7 and 8 required a crab angle in the approach leg with the more favorable parallel currents after the turn. Scenario 8 allows the most favorable turn conditions. The crab angle in the approach leg decreases the heading change required by the turn, the buoy positions encourage an early start, and the current forces act to quickly orient the ship parallel to the channel early in the second leg.

The effects of the current, acting both on the ship and on the buoys' positions, are apparent in the performance data in Table 9. In Scenario 7 the current facilitates Leg 1 recovery, taking the ship to the centerline. Trackkeeping in Leg 1 shows the effects of an overshoot of the centerline. The turn is initially difficult because the crab angle in the approach increased the heading change needed and the buoys encouraged a late start. The mean and standard deviation are fairly high, reflecting this difficulty. Once past the turn apex, the current acts to quickly orient the ship parallel to the channel. Note that B', one half of the adjusted beam, shows this orientation. The resulting RRF shows a moderate turn. Recovery is very good. Recovery during the experiment was so good that the scenario was terminated early; evaluating trackkeeping would have been trivial.

TABLE 8. COMPARISON OF CURRENT/BUOY DISPLACEMENT DIRECTION OF 341°T (SCENARIO 4) WITH 161°T (SCENARIO 6)

	341°T (SCENARIO 4)	161°T (SCENARIO 6)
Leg 1 Recovery Region[1] *		
	(Following Current)	(Head Current)
MN[2]	4	-23
SD[3]	29	59
(B'[4]	42.5)	42.5)
RRF[5]	0.0000	0.0008
Leg 1 Trackkeeping Region **		
	(Following Current)	(Head Current)
MN	-6	-30
SD	28	64
(B'	42.5)	42.5)
RRF	0.0000	0.0028
Turn Pullout *		
	(Current to Right)	(Current to Left)
MN	173	-69
SD	62	88
(B'	67)	67)
RRF	0.4364	0.0971
Leg 2 Recovery Region *		
	(Current to Right)	(Current to Left)
MN	133	-148
SD	81	63
(B'	67)	67)
RRF	0.2676	0.2877
Leg 2 Trackkeeping Region *		
	(Current to Right)	(Current to Left)
MN	97	-144
SD	84	71
(B'	67)	67)
RRF	0.1543	0.2912
RRFW[6]	0.6509	0.5458

* Significant differences between means in this region. See Appendix E.
** Significant differences between standard deviations in this region. See Appendix E.

NOTES: See Table 6

TABLE 9. COMPARISON OF CURRENT/BUOY DISPLACEMENT DIRECTION OF 306°T (SCENARIO 7) WITH 126°T (SCENARIO 8)

	306°T (SCENARIO 7)	126°T (SCENARIO 8)
Leg 1 Recovery Region[1] * **		
	(Current to Left)	(Current to Right)
MN[2]	-81	136
SD[3]	25	73
(B'[4]	67)	67)
RRF[5]	0.0000	0.2643
Leg 1 Trackkeeping Region * **		
	(Current to Left)	(Current to Right)
MN	-159	146
SD	42	103
(B'	67)	67)
RRF	0.2877	0.3601
Turn Pullout *		
	(Following Current)	(Head Current)
MN	160	-12
SD	70	53
(B'	42.5)	42.5)
RRF	0.2483	0.0001
Leg 2 Recovery Region *		
	(Following Current)	(Head Current)
MN	73	-13
SD	32	35
(B'	42.5)	42.5)
RRF	0.0000	0.0000
RRFW[6]	0.4646	0.5946

* Significant differences between means in this region. See Appendix E.
** Significant differences between standard deviations in this region. See Appendix E.

NOTES:
1. See Section 4.4 for a description of the selection of data for the region.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).
   The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.
6. RRFW: waterway relative risk factor. See Section 4.5.

Scenario 8 shows the effects of current and displaced buoys in the first leg. The mean track never achieves the centerline because some pilots just hold their position against the current. The standard deviation goes up as some pilots anticipate the turn and start over to the left. Performance in the turn is very good. Here, the crab angle decreased the needed heading change, the buoy positions encouraged an early start, and current oriented the ship to the channel. The RRF in the turn is the lowest ever measured on this project. Recovery is very good with a low RRF; trackkeeping was not evaluated.

5.5 AID ARRANGEMENTS

Of the variety of aid arrangements evaluated in the earlier phase of the project, one relatively high-performing arrangement was selected for this experiment. Scenario 1 here employed three aids in the turn and gated aids at 1 1/4 nautical mile intervals in the straight away. Also included in this experiment was a lower-density, lower-performing arrangement from the earlier phase. Scenario 2 here employed one aid at the inside apex of the turn and staggered aids at intervals of 1 1/4 nautical miles on a side in the straightaway. Both scenarios had fixed aid positions and decreasing current to permit comparison to earlier findings with those conditions. The two aid arrangements were repeated with the displaced aid position and constant current of the present experiments. These two additional conditions, Scenarios 4 and 9, provide an evaluation of the generality of the relative performance of the two aid arrangements with new environmental conditions. The conditions in the four scenarios are summarized in Table 4 and illustrated in Appendix B.

5.5.1 Comparison of Higher and Lower Density of Fixed Aids: Scenarios 1 and 2

The comparison between the higher-density aid arrangement, three aids in the turn and gated aids in the straightaway, and the lower-density aid arrangement, one aid in the turn and staggered aids in the straightaway, is presented in Table 10. The relative performance does not appear as expected. Leg 1 performance is identical in the two scenarios. In the turn pullout Scenario 2, the low-density arrangement, shows a slightly smaller mean and slightly longer standard deviation, that together result in a slightly lower RRF value. In Leg 2 trackkeeping, Scenario 2 shows a mean to the left of the centerline and a smaller standard deviation that together result in a lower RRF value.

The left-of-center mean during trackkeeping is the key to an interpretation of the lower RRF values for Scenario 2. Given the long-spaced, staggered aids, the pilots are "buoy-hopping," approaching first one buoy, then reversing to approach the next on the other side of the channel. The mean track plotted on page D-5 shows this technique. It keeps the ship inside a sparely-marked channel, without the pilots having any good

TABLE 10. COMPARISON OF HIGHER DENSITY OF FIXED AIDS (SCENARIO 1) WITH LOWER DENSITY OF FIXED AIDS (SCENARIO 2)

	HIGHER DENSITY (SCENARIO 1)	LOWER DENSITY (SCENARIO 2)
Leg 1 Recovery Region[1]		
MN[2]	4	3
SD[3]	40	39
(B'[4]	42.5	42.5
RRF[5]	0.0000	0.0000
Leg 1 Trackkeeping Region		
MN	-6	-5
SD	41	40
(B'	42.5)	42.5)
RRF	0.0000	0.0000
Turn Pullout		
MN	144	130
SD	45	54
(B'	67)	67)
RRF	0.1922	0.1792
Leg 2 Recovery Region		
MN	114	105
SD	60	65
(B'	54.8)	54.8)
RRF	0.0885	0.0823
Leg 2 Trackkeeping Region * **		
MN	-6	-48
SD	98	73
(B'	54.8)	54.8)
RRF	0.0459	0.0221
RRFW[6]	0.2975	0.2634

* Significant differences between means in this region. See Appendix E.
** Significant differences between standard deviations in this region. See Appendix E.

NOTES:
1. See Section 4.4 for a description of the selection of data for the region.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B' : calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).
   The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.
6. RRFW: waterway relative risk factor. See Section 4.5.

knowledge of the edges or the centerline. This technique has been seen with this aid arrangement in earlier experiments.[5,6] In all cases, the pilots considered it unsafe. With little knowledge of their position in the channel, they could not expect to respond safely to traffic, changes in wind or current, emergencies, etc. In the present experiment the buoy-hopping technique was reinforced by the experimental context. While the aids in Scenario 2 were fixed, in other scenarios they were not. The pilots developed a concentration on the buoys that were in "good water," generally on the "black" side. With a single turnpoint buoy, "I stayed close to the black buoy. It was all I had." Staying close to the single black turnpoint buoy resulted in the low RRF in the turn pullout.

5.5.2 Comparison of Higher and Lower Density of Floating Aids: Scenarios 4 and 9

The comparison between the two aid arrangements was repeated with the floating aids and constant current introduced in this experiment. Performance in Scenarios 4 and 9 is summarized in Table 11. Again, performance shows evidence of buoy-hopping, with some regions having lower RRF values for the lower-density arrangement. Performance also shows evidence of the displaced buoys and constant current. In Leg 1 of Scenario 9, there was a tendency to prepare for the difficult turn by making an early approach to the turnpoint buoy. This tendency resulted in a high RRF value for the trackkeeping region, but was rewarded by a lower RRF value for the turn pullout then was the case for Scenario 4. In Leg 2 performance in the trackkeeping region of Scenario 9 shows a lower RRF then that for Scenario 4. There was again a tendency to approach the buoy on the opposite side of the centerline, but this time the continuing crosscurrent discouraged a crossing of the centerline. Neither aid arrangement resisted a deterioration of performance with displaced aids and a continuing crosscurrent.

---

[5] Smith, M.W. and W.R. Bertsche. "Aids to Navigation Principal Findings Report on the Channel Width and Related Variables on Piloting Performance." CG-D-54-81. U.S. Coast Guard, Washington, D.C., December 1981. NTIS AD-A111337.

[6] Bertsche, W.R., D.A. Atkins, and M.W. Smith. "Aids to Navigation Principal Findings Report on the Ship Variables Experiment: The Effect of Ship Characteristics and Related Variables on Piloting Performance." CG-D-55-81. U.S. Coast Guard, Washington, D.C., November 1981. NTIS AD-A108771.

* Note: the left-hand buoys in the simulation were green in keeping with the present conventions of the International Association of Lighthouse Authorities and the United States Coast Guard, but the pilots persist in calling the left side the "black" side.

TABLE 11. COMPARISON OF HIGHER DENSITY OF FLOATING AIDS (SCENARIO 4) WITH LOWER DENSITY OF FLOATING AIDS (SCENARIO 9)

	HIGHER DENSITY (SCENARIO 4)	LOWER DENSITY (SCENARIO 9)
Leg 1 Recovery Region[1]		
MN[2]	4	6
SD[3]	29	43
(B'[4]	42.5	42.5
RRF[5]	0.0000	0.0000
Leg 1 Trackkeeping Region **		
MN	-6	26
SD	28	63
(B'	42.5)	42.5)
RRF	0.0000	0.0000
Turn Pullout		
MN	173	152
SD	62	55
(B'	67)	67)
RRF	0.4364	0.2877
Leg 2 Recovery Region		
MN	133	153
SD	81	67
(B'	67)	67)
RRF	0.1543	0.3300
Leg 2 Trackkeeping Region		
MN	97	65
SD	84	108
(B'	67)	67)
RRF	0.1543	0.1486
RRFW[6]	0.6500	0.5946

* Significant differences between means in this region. See Appendix E.
** Significant differences between standard deviations in this region. See Appendix E.

NOTES:
1. See Section 4.4 for a description of the selection of data for the region.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).
   The value used here for B' uses the standard ship dimensions taken from the *SRA Design Manual*, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.
6. RRFW: waterway relative risk factor. See Section 4.5.

5.6 SUMMARY OF RESULTS

- The displacement of floating aids from their assigned position at the channel edge resulted in a deterioration in performance.
- Increasing the distance of displacement increased deterioration because pilots were able to compensate for some, but not all, of the displacement.
- When the displacement of floating aids was accompanied by an increased current acting on the ship, the deterioration was considerable.
- Changes in the direction of current acting on both the floating aids and the ship resulted in very major differences in performance.
- Displacement of aids from their assigned positions resulted in deterioration with both aid arrangements evaluated.
- With a low-density, staggered arrangement there was a tendency to "buoy-hop," rather than to attempt to achieve a centerline track.

Section 6

PROJECT RESEARCH ISSUES

6.1 INTRODUCTION

Performance data from each simulator experiment in the Waterway project is intended to contribute to the pool of data on which the SRA Systems Design Manual is based. Because the data come from experiments that differed to a greater or lesser extent in simulator, ship model, pilot group, context effects, etc.; data cannot be added to the pool without consideration of the effects of these differences on measured performance. This section will discuss ways in which the present experiment's conditions and resulting performance differ from the general pool and will recommend ways in which to use the present data in the Manual's design process.

6.2 FIXED AIDS -- POSSIBLE BIAS TO DESIGN DATA?

A concern has been expressed that the fixed aids, always at their exact assigned positions in earlier experiments, might have resulted in a bias to the resulting measured performance. Possibly, fixed aids result in better performance, or lower risk, than would result from evaluating aid arrangements with floating aids. Scenarios were included in the present experiment to examine this possibility.

Performance data for fixed and floating aids are compared in Table 12. Data are presented for four scenarios in the turn pullout where the current direction (set) and speed (drift) are the same: 341°T at 0.9 knots. Performance is indeed poorer or risk higher with floating aids. This difference holds for the two different aid arrangements evaluated.

The question remains as to whether the use of fixed aids in the earlier simulations resulted in the over-estimation of aid system/waterway performance, or the under-estimation of expected risk, as it might occur at sea with floating aids. The aids in the earlier simulations were fixed at their assigned positions, but that was only one of a number of factors that affected performance. Each scenario contained a mix of piloting tasks, including relatively-difficult shiphandling. The 35-degree turn, slow transit speed of approximately 6 knots, and crosstrack wind and current exaggerated the difficulty of the turn and its recovery. These "design conditions" built in a margin of safety for low-frequency or unanticipated events when applied to real-world waterways. The planned design conditions result in a range of values from 0.0000 to values implying almost total certainty of grounding. The above claim, that "design conditions" provide a safety margin compared to expected at-sea conditions, is supported by available data from an earlier phase of the project. A sample of performance data collected at sea, and data from a simulation designed to match it, is presented in Figure 7. The figure is a reproduction of a table from the Design Manual. Note that realistic, frequent shiphandling conditions result in RRF values of 0.0000. The design conditions used in the simulator experiments allow a margin of safety -- and a differentation among a variety of conditions.

TABLE 2-7. SAMPLE VALIDATION DATA FOR TURN PULLOUT AND RECOVERY IN NARRAGANSETT BAY

	At Sea	Simulator
pullout, 1900 feet beyond apex		
MN[1]	36.71 left	1.94 left
SD[2]	33.23	42.43
NS[3]	3.11	5.53
NP[4]	5.9	5.44
RRF[5]	0.0000	0.0000
recovery, 2500 feet beyond apex		
MN	10.85 left	32.19 right
SD	17.49	45.59
NS	15.34	4.94
NP	14.10	6.35
RRF	0.0000	0.0000
trackkeeping, 4750 feet beyond apex		
MN	0.61 right	27.78 right
SD	19.17	45.54
NS	34.40	5.04
NP	13.46	6.26
RRF	0.0000	0.0000

NOTES:

1. Mean is in feet from the centerline of the channel.

2. SD, standard deviation, is in feet.

3. NS is the number of standard deviations that will fit in the channel to starboard of the extreme point of ship. It is taken from the relative risk factor calculation described in Section 2.6.3

4. NP is the number of standard deviations that will fit in the channel to port of the extreme point of ship. It is taken from the relative risk factor calculation described in Section 2.6.3

5. RRF is the relative risk factor, the relative probability of grounding described in Section 2.6

Figure 7: "Realistic" Performance Data Reproduced From Design Manual

TABLE 12. COMPARISON OF FIXED AND FLOATING AIDS, AT TURN PULLOUT

	FIXED AIDS	FLOATING AIDS
3-Buoy Turn, Gated		
	(Scenario 1)	(Scenario 4)
MN[2]	144	173
SD[3]	45	62
(B'[4]	67)	67)
RRF[5]	0.1922	0.4364
1-Buoy Turn, Staggered		
	(Scenario 2)	(Scenario 9)
MN	130	152
SD	57	55
(B'	67)	67)
RRF	0.1792	0.2877

NOTES:

1. See Section 4.4 for a description of the selection of data for the region.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).

   The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.

6.3 RELATIVE PERFORMANCE OF HIGHER- AND LOWER-DENSITY AID ARRANGEMENTS

Over a number of experiments, higher-density aid arrangements have resulted in better performance than have lower-density arrangements. The guidelines and performance data of the Design Manual reflect this relative performance. Two different aid arrangements from earlier experiments were included in the present experiment. Scenario 1 was a higher-density arrangement; Scenario 2, a lower-density arrangement. (These arrangements are illustrated by chartlets in Appendix B.) The unexpected relative performance of these two scenarios was described in Section 5.5 of the present report. In this experiment performance, as measured by the RRF, was "better" for Scenario 2 than for Scenario 1.

Performance for Scenarios 1 and 2 is summarized in Table 13, along with performance for the same scenarios in the earlier Targets of Opportunity experiment. In the earlier experiment Scenario 1 showed the expected relatively-better performance than Scenario 2. This side-by-side presentation of data from the two experiments supports the point made in Section 5.5 of the present report: that the relatively good performance of Scenario 2 is the result of the present experimental context. The current and floating aids in the present experiment encouraged the pilots to adapt a strategy of avoiding the down-current side of the channel, where the aids were not in "good water". They maintained this strategy even in these scenarios where the aids were fixed at the channel edge and the current decreased in velocity. Note that performance in Scenario 1 in Leg 2 with a decreasing crosscurrent is better in this experiment than in the earlier experiment, in which the experimental context did not encourage such a strategy. In Scenario 2 the strategy of avoiding the down current side is exaggerated by the low density of aids and the increase in the uncertainty of the channel edge there. The result is the unexpectedly "good" ship tracks of Scenario 2 in the present experiment. There is no reason to assume that these ship tracks are more representative of the real-world performance of low-density arrangements than are poorer tracks that have been found in a number of earlier experiments. No change will be made to the Manual's design and evaluation process on the basis of this latest result.

6.4 LEVEL OF OVERALL PERFORMANCE FOR AN EXPERIMENT

The overall level of performance in this experiment was poorer, or the general level of RRF values was higher, than was the case in the experiments of the earlier phase of the project on which the Manual is based. The same poorer level of performance was found for the Targets of Opportunity experiment, the first experiment in this present phase. In Section 6 of the report for that experiment, it was concluded that the primary reason for the poorer performance was a different ship model. In these two recent experiments, a tanker was modeled fully-loaded, rather than in ballast, as had been the case for the principal ship in the earlier phase.

Because of this difference in the overall level of performance, the findings of the present experiment cannot be added to the performance data in the Manual in any simple way. During this phase of the Waterway project,

TABLE 13. RELATIVE PERFORMANCE OF AID ARRANGEMENTS OVER EXPERIMENTS

	TARGETS OF OPPORTUNITY		POSITIONING	
	3-aid turn, gated aids (Scenario 1)	1-aid turn, staggered aids (Scenario 2)	3-aid turn, gated aids (Scenario 1)	1-aid turn, staggered aids (Scenario 2)
Recovery Without Crosscurrent[1] **				
MN[2]	21.40	20.10	4	3
SD[3]	21.56	45.70	40	39
(B[4]	42.5)	42.5)	42.5)	42.5)
RRF[5]	0.0000	0.0000	0.0000	0.0000
Trackkeeping Without Crosscurrent				
MN	-10.89	32.72	-6	-5
SD	30.77	79.33	41	40
(B	42.5)	42.5)	42.5)	42.5)
RRF	0.0000	0.0151	0.0000	0.0000
Turn Pullout				
MN	150.24	174.82	144	130
SD	45.83	72.55	45	57
(B	67)	67)	67)	67)
RRF	0.2389	0.4562	0.1922	0.1792
Recovery With Crosscurrent **				
MN	143.83	161.97	114	105
SD	47.31	49.96	60	65
(B	54.8)	58.8)	54.8)	54.8)
RRF	0.1379	0.2514	0.0885	0.0823
Trackkeeping With Crosscurrent			* **	
MN	91.36	39.65	-6	-48
SD	72.80	84.59	98	73
(B	54.8)	54.8)	54.8)	54.8)
RRF	0.0764	0.0356	0.0459	0.0221
RRFW[6]	0.3940	0.6133	0.2975	0.2634

* Significant differences in mean in this region (within experiment)

** Significant differences in standard deviation in this region (within experiment)

NOTES: See Table 6

an analysis will be done of the contribution of ship performance to overall waterway performance. A revision is planned to the Manual to incorporate new findings. Until then, to make the present experiment immediately useful to the waterway aid system designer, interim guidelines will be developed in the remainder of Section 6 and presented in Section 7.

6.5 USE OF THE EXPERIMENTAL DATA FOR INTERIM GUIDELINES

6.5.1 Introduction

Scenario 1 in this experiment provides a new baseline of performance. It can be considered a stand-in in this experiment for the Design Manual performance data, collected in earlier simulator evaluations. It is an evaluation of an aid arrangement and the scenario conditions of the earlier phase, using the simulator, ship model, and pilot group of the present phase; and evaluated within the context of the present experiment. Any differences between Scenario 1 and other scenarios in the present experiment are attributable to the experimental variables: the distance of buoys from their assigned position and the direction of current and buoy displacement. In the rest of Section 6.5 the relationships between Scenario 1 and other scenarios in the experiment will be described by variable and by region of the waterway. In Section 7 rules will be provided for adjusting Design Manual data according to these relationships.

Available comparisons between Scenario 1 and other conditions evaluated are summarized in Table 14. Statistical comparisons are provided in Appendix F. To summarize those tests, *differences due to buoy distances* are generally not significant; differences due to buoy/current direction are generally significant.

6.5.2 Accuracy Classification (Distance)

The accuracy classification of buoys was reported in Section 5.3 to affect ship track performance in the Leg 2, where the buoys were displaced some distance perpendicular to the channel edge. The observed relationships between the perpendicular distance and observed performance is fitted by a straight line in the next several tables.

Performance in the turn region is shown in Table 15. The first row of numbers are the distances of buoys perpendicular to the channel edge in the evaluated conditions. In the second row the observed means are taken from Tables 6 and 7. The fitted values and slope of the line appear next. A line was also fitted to the more gradual increase in the associated standard deviations as a function of crosstrack displacement of the buoys.

Performance in the recovery region is summarized in Table 16. The observed means come from Table 7. The fitted values and the slope of the line appear next. A line was also fitted to the associated standard deviations.

Performance in the trackkeeping region is summarized in Table 17. The observed means come from Table 7. The fitted values and the slope of the line come next. No line was fitted for the associated standard deviation. They are assumed to have a slope of zero.

TABLE 14. ADDITIONAL COMPARISONS SUPPORTING INTERIM GUIDELINES

EFFECT	SCENARIOS
Baseline Conditions Versus Varying Buoy Distances	
Assigned Position Versus 41 Feet Perpendicular Distance	1 vs 3
Assigned Position Versus 69 Feet Perpendicular Distance	1 vs 4
Assigned Position Versus 103 Feet Perpendicular Distance	1 vs 5
Baseline Conditions Versus Varying Buoy/Current Directions	
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 341°T	1 vs 4
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 161°T	1 vs 6
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 306°T	1 vs 7
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 126°T	1 vs 8

6.5.3 Channel/Current Orientation (Direction)

The relative orientation of channel and current was reported in Section 5.4 to have major effects on waterway performance. The observed performance discussed in that section is presented in the next several tables arranged by regions. The intention here is to compare each variation in channel/current orientation to region performance in Scenario 1, the stand-in for Design Manual conditions. The differences between Scenario 1 and each variation will guide the adjustments to be made to Manual data to represent differing channel/current orientation.

The effects of channel/current orientation in the turn region are shown in Table 18. The baseline Scenario 1 appears at the top. The turn from a following to a crosscurrent with floating aids appears in the next row to the left. With floating aids both the mean and the standard deviation are larger than in the baseline condition and the RRF more than doubles. This condition maximizes the risk of the turn; it is the "worst-case". The head-to-crosscurrent turn shows a pullout with the crosscurrent direction acting to keep the ship in the channel. The mean is substantially to the inside of that in baseline Scenario 1, even to the inside of the centerline. Despite an increase in standard deviation over Scenario 1, there is a substantial decrease in RRF in this condition.

TABLE 15. EFFECT OF DISTANCE OF BUOYS PERPENDICULAR TO CHANNEL EDGE IN TURN REGION

Distance of Buoys Perpendicular to Channel Edge (Feet)[1]			
Assigned Position	41	69	103
THE MEANS			
Observed Means (Feet)[2]			
144	177	173	196
Fitted Values (Feet)[3]			
148	167	179	195
Slope of Fitted Line for Means			
0.46			
THE STANDARD DEVIATION			
Observed Standard Deviations (Feet)[2]			
45	61	62	75
Fitted Values (Feet)[3]			
46	57	65	75
Slope of Fitted Line for Standard Deviations			
0.27			

NOTES:

1. Distances are for Scenarios 1, 3, 4, and 5 in Leg 2. The distance of buoys perpendicular to the channel edge when current is not parallel to channel:

   Distance of buoys perpendicular to channel edge = sin θ x distance from assigned position.

   Where θ = current direction - channel heading.

2. Observed values are taken from Table 7, Section 5.2 and Table 7, Section 5.3.

3. Straight line for fitted by method of least squares.

TABLE 16. EFFECT OF DISTANCE OF BUOYS PERPENDICULAR TO CHANNEL EDGE IN RECOVERY REGION

Distance of Buoys Perpendicular to Channel Edge (Feet)[1]			
Assigned Position	41	69	103
THE MEANS			
Observed Means (Feet)[2]			
—	139	133	149
Fitted Values (Feet)[3]			
128	135	139	146
Slope of Fitted Line for Means			
0.17			
THE STANDARD DEVIATION			
Observed Standard Deviations (Feet)[2]			
—	53	81	76
Fitted Values (Feet)[3]			
45	60	69	81
Slope of Fitted Line for Standard Deviations			
0.35			

NOTES:

1. Distances are for Scenarios 1, 3, 4, and 5 in Leg 2. The distance of buoys perpendicular to the channel edge when current is not parallel to channel:

   Distance of buoys perpendicular to channel edge = sin θ x distance from assigned position.

   Where θ = current direction - channel heading.

2. Observed values are taken from Table 7, Section 5.3.

3. Straight line for fitted by method of least squares.

TABLE 17. EFFECT OF DISTANCE OF BUOYS PERPENDICULAR TO CHANNEL EDGE IN TRACKKEEPING REGION

Distance of Buoys Perpendicular to Channel Edge (Feet)[1]			
Assigned Position	41	69	103
THE MEANS			
Observed Means (Feet)[2]			
—	30	97	80
Fitted Values (Feet)[3]			
15	47	67	93
Slope of Fitted Line for Means			
0.75			
THE STANDARD DEVIATIONS			
Observed Standard Deviations (Feet)[2]			
—	81	84	84

NOTES:

1. Distances are for Scenarios 1, 3, 4, and 5 in Leg 2. The distance of buoys perpendicular to the channel edge when current is not parallel to channel:

   Distance of buoys perpendicular to channel edge = sin θ x distance from assigned position.

   Where θ = current direction - channel heading.

2. Observed values are taken from Table 7, Section 5.3.

3. Straight line for fitted by method of least squares.

TABLE 18. EFFECT OF CHANNEL/CURRENT ORIENTATION IN THE TURN REGION

FIXED AIDS	
FOLLOWING TO CROSSCURRENT (SCENARIO 1)	
DL[1]	3
MN[2]	144
SD[3]	45
(B'[4]	67)
RRF[5]	0.1922

FLOATING AIDS			
FOLLOWING TO CROSSCURRENT (SCENARIO 4)		HEAD TO CROSSCURRENT (SCENARIO 6)	
DL	3	DL	3
MN	173	MN	-69
SD	62	SD	88
(B'	67)	(B'	76)
RRF	0.4364	RRF	0.0971
CROSS- TO FOLLOWING CURRENT (SCENARIO 7)		CROSS- TO HEAD CURRENT (SCENARIO 8)	
DL	2	DL	2
MN	160	MN	-12
SD	70	SD	53
(B'	42.5)	(B'	42.5)
RRF	0.2483	RRF	0.0001

NOTES:

1. DL: data lines as described in Section 4.2.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).

   The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.

The two remaining turns are from a leg with a crosscurrent into one with a parallel current. Note that maximum effect of the pullout appears at Data Line 2, rather than 3. That is, with a parallel current the ship has made its maximum excursion toward the channel edge and is ready to return to the centerline earlier. Note also that B' is one half the ship's beam; the ship enters the new leg oriented to the channel edges. The lower value for B' reduces the RRF values. In the cross-to-following current condition, the mean and standard deviation are larger than they are in Scenario 1 and the resulting RRF is larger. In the cross-to-head current condition, the mean is well within what it was in Scenario 1, the mean is similar and the resulting RRF is very small.

The effects of channel/current orientation in the recovery region are shown in Table 19. The baseline Scenario 1 appears at the top. The condition in the top row to the left is with crosscurrent to the outside of the preceding turn in that transit. The floating aids and current that does not drop off result in a larger mean, larger standard deviation, larger B', and therefore substantially larger RRF than that for Scenario 1. With the crosscurrent to the inside, the mean is negative and larger than that in Scenario 1, the standard deviation similar, the B' larger, and the RRF larger. The two conditions of recovery in a parallel current show very low risk. The means are smaller than that in Scenario 1, with the mean of recovering from a turn into a head current very small. The small standard deviations and B' of one half ship's beam resulting in very low RRF values.

The effects of channel/current orientation in the trackkeeping region are shown in Table 20. The baseline Scenario 1 appears at the top. The condition in the top row to the left has crosscurrent on the port side. With the floating aids and crosscurrent that does not drop off the trackkeeping mean does not achieve the centerline as it does in the baseline scenario. The standard deviation is similar to that in the baseline scenario. B' remains high because of the continuing need for a crab angle. The resulting RRF is higher than in the baseline condition. The condition with crosscurrent on the starboard side shows a larger mean than the baseline condition and to the down-current side of the centerline. It shows a similar standard deviation, and a B' that shows the need for a continuing a crab angle. The resulting RRF is again larger than in the baseline condition. Trackkeeping with a head or following current was not evaluated in the experiment. Note that recovery region performance shown in Table 18 had already reached an RRF level of 0.0000.

TABLE 19. EFFECT OF CHANNEL/CURRENT ORIENTATION IN THE RECOVERY REGION

FIXED AIDS	
CROSSCURRENT TO OUTSIDE (SCENARIO 1)	
DL[1]	6
MN[2]	114
SD[3]	60
(B'[4]	54.8)
RRF[5]	0.0885

FLOATING AIDS			
CROSSCURRENT TO OUTSIDE (SCENARIO 4)		CROSSCURRENT TO INSIDE (SCENARIO 6)	
DL	6	DL	15
MN	133	MN	-148
SD	81	SD	63
(B'	67)	(B'	67)
RRF	0.2676	RRF	0.2877
FOLLOWING CURRENT (SCENARIO 7)		HEAD CURRENT (SCENARIO 8)	
DL	6	DL	6
MN	73	MN	-13
SD	32	SD	35
(B'	42.5)	(B'	42.5)
RRF	0.0000	RRF	0.0000

NOTES:

1. DL: data lines as described in Section 4.2.
2. MN: crosstrack mean in feet. Positive values are to right of centerline.
3. SD: crosstrack standard deviation in feet.
4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).

   The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.
5. RRF: relative risk factor. See Section 4.4.

TABLE 20. EFFECT OF CHANNEL/CURRENT ORIENTATION IN THE TRACKKEEPING REGION

FIXED AIDS

CROSSCURRENT TO OUTSIDE (SCENARIO 1)

DL[1]	20
MN[2]	-6
SD[3]	98
(B'[4]	54.8)
RRF[5]	0.0459

FLOATING AIDS

CROSSCURRENT ON PORT SIDE (SCENARIO 4)

DL	24
MN	97
SD	84
(B'	67)
RRF	0.1543

FOLLOWING CURRENT (SCENARIO 7)

DL	6
MN	73
SD	32
(B'	42.5)
RRF	0.0000

CROSSCURRENT ON STARBOARD SIDE (SCENARIO 6)

DL	16
MN	-144
SD	71
(B'	67)
RRF	0.2912

HEAD CURRENT (SCENARIO 8)

DL	6
MN	-13
SD	35
(B'	42.5)
RRF	0.0000

NOTES:

1. DL: data lines as described in Section 4.2.

2. MN: crosstrack mean in feet. Positive values are to right of centerline.

3. SD: crosstrack standard deviation in feet.

4. B': calculated as (length/2)x(crosstrack current velocity/transit speed) + (beam/2).

   The value used here for B' uses the standard ship dimensions taken from the SRA Design Manual, Table 5-3. This was done in preparation for including these findings in the manual.

5. RRF: relative risk factor. See Section 4.4.

Section 7

INTERIM GUIDELINES

7.1 INTRODUCTION

This section is intended to serve two purposes. As the final section in the POSITIONING Experiment Report, it provides recommendations for treating the effects of the variables investigated on the performance of the waterway system. It also provides "interim guidelines" for the application of the findings to the design and evaluation process of the SRA Systems Design Manual. The overall plan for the Waterway Study is to incorporate findings from all the simulator experiments in a revision of the Manual at the end of the present phase. Until then, this section allows immediate application of the findings of the experiment.

The Manual provides a primary, general-purpose design and evaluation process for a waterway. The procedures and the performance data provided there allow for conservatism, or a margin of safety, to allow for difficult or low-frequency or unexpected conditions. The general-purpose analysis will not underestimate the risk to be expected in a waterway with floating aids and more typical shiphandling conditions.

The analysis described in the section is meant not to replace, but to supplement, the Manual. It is written with the assumption that the waterway designer applying these guidelines is familiar with the Manual and has already done an analysis of the subject waterway using it. The guidelines here provide for a secondary, special-purpose analysis of a waterway where floating aids, displaced from their assigned positions primarily by current, are a major consideration in a transit. The procedures here allow the designer to quantify or "model" the effects of floating aids and current from region to region, according to conditions in that region.

7.2 POSSIBLE OBJECTIVES OF THIS ANALYSIS

Examples of possible objectives to be served by the supplementary analysis follow:

1. To prioritize regions of a waterway (or whole waterways of a district) for attention on the basis of the shiphandling difficulty posed by floating aids and currents. The procedures here allow a greater sensitivity to conditions from region to region than does the Manual. Generally, RRF values calculated here will be higher, because adjustment is made for the distance of buoys off the channel edge and resulting displacement of ship tracks. However, in some regions where current direction is favorable to the ship maneuvers being performed, RRF values may be lower than those calculated using the Manual.

2. NOT to identify appropriate arrangements when aids are floating: the procedures here are not applied differentially to different arrangements and will not result in definite recommendations for particular arrangements.

3. To evaluate the effects of improving position information in a region by extraordinary efforts to position buoys on the channel edge; or by using articulated beacons, fixed structures, or ranges.

4. To evaluate the effects of operational restrictions. When tidal currents substantially change conditions in a waterway, improvements in performance may be achieved by restricting transits to slack current or to favorable current directions for difficult portions of the waterway.

5. To evaluate the effects of alternative channel orientation. There may be opportunities to move segments of a waterway or to recommend alternative channel orientations to the United States Army Corps of Engineers.

7.3 APPROPRIATE APPLICATION OF THE ANALYSIS

7.3.1 Conditions of Data Collection

The objective of the experiment was to evaluate the effects of floating aids on performance in a waterway. In preliminary planning it was decided not to evaluate the effects of individual aids off-station, but instead to evaluate the more major effects of groups or systems of aids providing inaccurate or biased information to the mariner. The Aids to Navigation Manual - Positioning was used to define the experimental variables. The primary variable was the distance of buoy displacement, a dimension dependent on possible error in the placement of the mooring and possible excursion around the mooring caused by current, wind, etc. Distances were selected to correspond to Accuracy Classifications A, B and C as defined in that manual. The secondary variable selected was direction of displacement. The manual states the positioning error is critical when its direction is perpendicular to the channel edge. In the experiment direction was varied by changing the orientation of the current to the channel. This mechanism resulted in straight-channel aids that had their major displacement perpendicular to the channel edge and aids in the critical turn region that were displaced both crosstrack and alongtrack. These conditions are illustrated on the following pages. By extension, the effects of the distance of displacement caused by current, etc. will differ, depending on direction.

The experiment was designed with a baseline Scenario 1 to represent the shiphandling conditions of the general body of performance data in the Design Manual. It has aids fixed at their assigned positions, with a certain amount of "conservatism" built into performance by the shiphandling conditions. The current followed in the first leg, exaggerated the forces of the turn pullout, and required a crab angle for recovery in the second leg. Ship speed was deliberately kept low to ensure the effectiveness of

the current forces. Other scenarios in this experiment were designed to vary distance or direction of buoy displacement. Differences between Scenario 1 and these other scenarios are reflected in the guidelines in the Section 7.4. In that subsection the waterway system designer is instructed to make adjustments to Design Manual data to approximate the expected effects of floating aids.

7.3.2 Distance of Buoy Displacement

The experimental scenarios were designed with the buoys' assigned positions at the exact channel edge and all buoys in a scenario displaced a uniform distance and direction by a uniform current. As a result, the actual positions of the buoys showed a constant bias in relation to the channel edge. In different scenarios the buoys appeared displaced by a distance appropriate for Accuracy Classifications A, B, or C. The displacements of the buoys in the turn are illustrated in Figure 8, repeated here from Section 5. The buoys' positions were the only differences among these three scenarios; current velocity was the same.

To approximate realistic performance, the pilots needed some information about buoy displacement. At sea they would have "local knowledge" about currents and, possibly, a view of landmass and fixed objects to help their judgment of position. To substitute for such information, the pilots were told that for a scenario the buoys would be displaced ______ yards by the current. Their problem was to estimate the location of the dredged channel and to maneuver the ship along their preferred track in the channel, despite the bias presented by the actual position of the buoys.

The pilots compensated, but partially, for the bias of the buoys. The mean of the tracks moved over some proportion of the distance of buoy displacement; and the standard deviation increased, showing less agreement among pilots on the appropriate track. Overall, there was an increase in RRF with the distance of buoy displacement.

The variable of distance of buoy displacement is expressed in the guidelines below as perpendicular distance from the channel edge. The measured response in ship tracks to this displacement is expressed as an adjustment to be made to the SRA Design Manual baseline data. This adjustment approximates performance that might have been observed if the aids had been floating for the conditions presented in the Manual.

7.3.3 Direction of Buoy Displacement

The direction of buoy displacement was varied by varying the orientation of current to the channel. Four scenarios were created by orienting the current (with parallel wind) to each of the two legs of the channel in each direction. The effect of current on the turn buoys is illustrated in Figure 9, repeated here from Section 5. The pilot was told the direction of current and buoy displacement, but he had other sources of this information. The visual scene showed a wake on the buoys in the appropriate direction and the current acted appropriately on the ship.

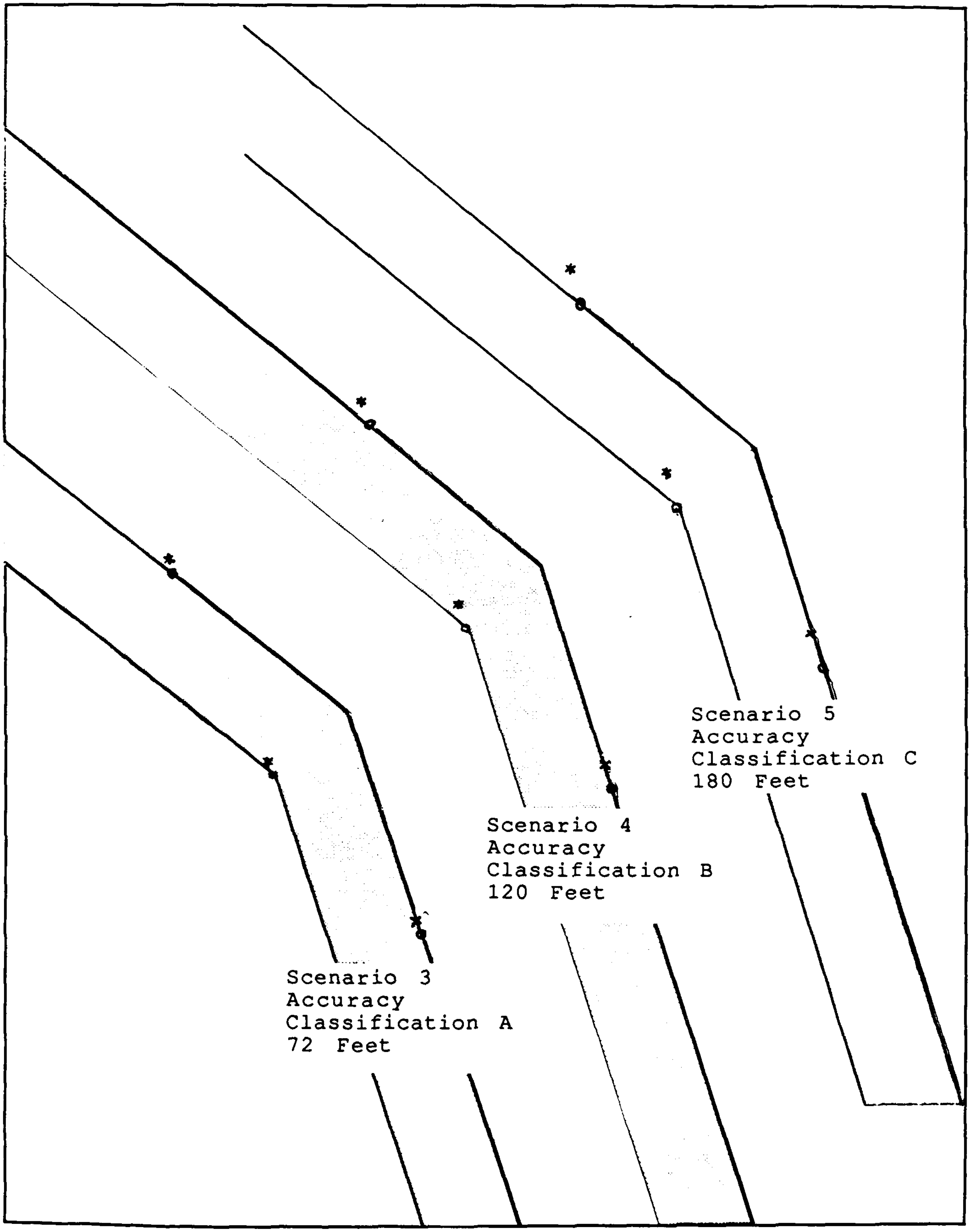


Figure 8: Buoy Displacements Representing Accuracy Classifications

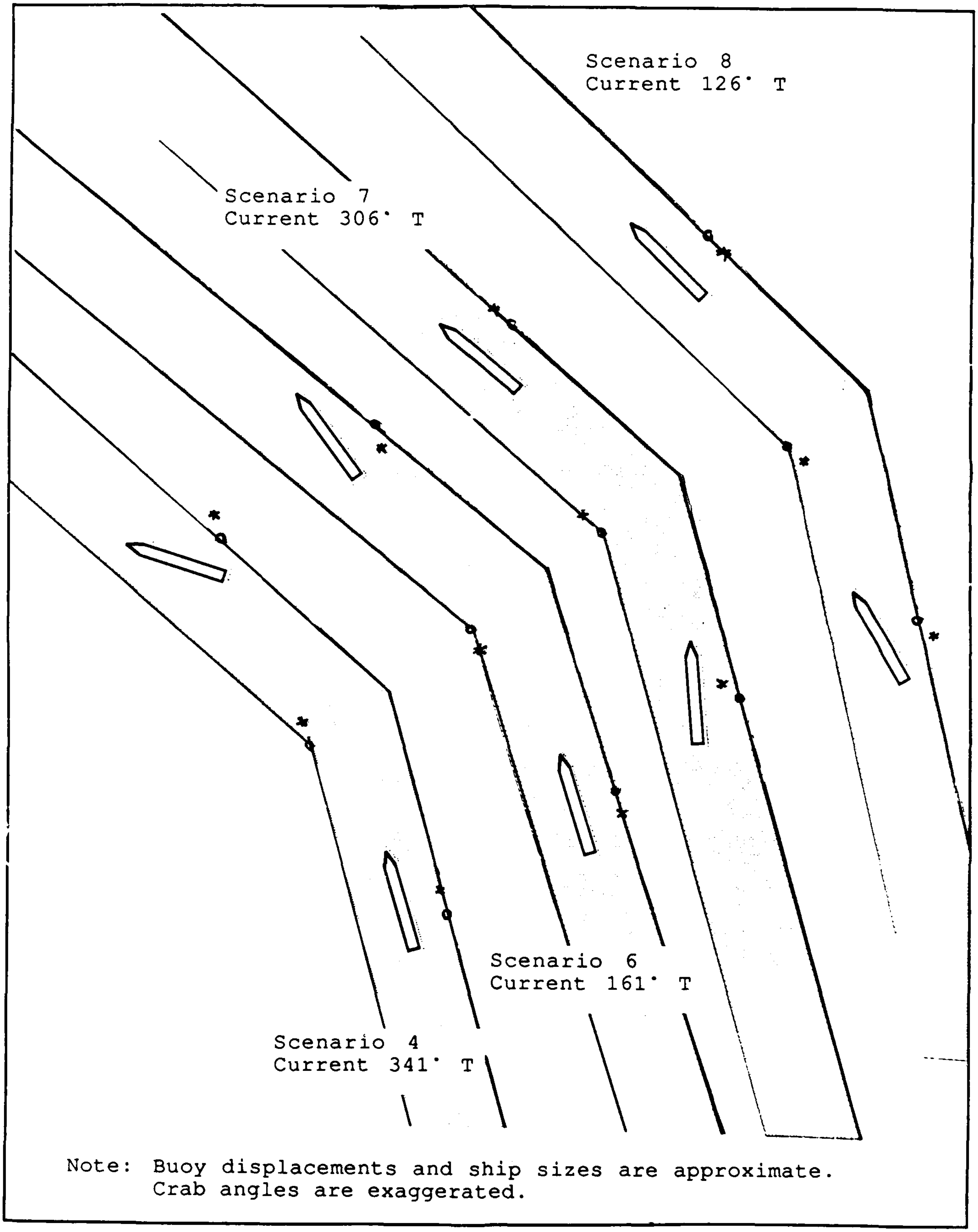


Figure 9: Buoy Displacements Representing Channel/Current Orientation

The forces on the buoys and on the ship, together, contribute to the difficulty of the situation. The first condition in Figure 9 is the "worst-case." The actual positions of the buoys encourage a late start to the turn and pullout that is to the outside; at the same time, current exaggerates turn forces, pushing the ship to the outside at pullout and requiring a crab angle for recovery. In the second condition the positions of the buoys encourage a more favorable early start to the turn. Current forces also act to keep the ship away from the channel edge, but still require a crab angle for recovery. Given the ship's transit speed and the current velocity, the required crab angles for both conditions were within the 2 to 5 degree range assumed to be a challenging but manageable task. The last two conditions require a crab angle in the approach leg, but the currents parallel to the channel in the second leg allow more favorable pullouts. The last condition allows an especially favorable turn. The crab angle in the approach decreases the heading change required by the turn, the buoy positions encourage an early start, and the current forces act to quickly orient the ship parallel to the channel in the second leg.

Measured performance showed major differences among these four conditions, affecting the means, the standard deviation, and the adjusted beam, and of course the resulting RRF. Differences in performances between the baseline Scenario 1, representing Design Manual shiphandling conditions, and these conditions were used to develop the following guidelines. Directions are provided for adjusting Manual baseline data to differing current conditions. If adjustments are to be made for buoy displacement direction, the amount of adjustment is determined by distance of buoy displacement.

7.4 PROCEDURES FOR THE ANALYSIS

The following steps used the findings of the POSITIONING experiment to adapt SRA Design Manual procedures to the floating buoy situation.

1. Collect the best information available on current set and drift in the waterway, or segment of waterway, of interest. If there are seasonal or tidal currents, select the worst-case conditions for analysis or analyze different conditions separately for comparison. (See objectives in Section 7.2). (Note that if the current requires a crab angle greater than 5 degrees to maintain a course, the RRF values calculated here will underestimate risk.)

2. Collect the best information on position for each buoy in the waterway of interest. The minimum useful information is the Accuracy Classification. If that is what is available, assume the buoy is displaced from an assigned position on the channel edge by the tolerances of that accuracy classification, in the direction of the current. Table 21 is copied from the Aids to Navigation Manual -- Positioning, showing those tolerances. Calculate the perpendicular distance of the buoy from the channel edge for each current condition of interest as follows:

distance of buoys perpendicular to channel edge = sin θ x distance from an assigned position on channel edge,

where θ = current direction - channel heading

TABLE 21. ACCURACY CLASSIFICATIONS OF SERVICE PROVIDED TO THE MARINER

Accuracy Classification	Tolerance
A	30 yds (27.4 m)
B	50 yds (45.7 m)
C	75 yds (68.6 m)
D	100 yds (91.4 m)
E	150 yds (137.2 m)
F	200 yds (182.9 m)
G	greater than 200 yds from AP

Where Accuracy Classification A through F would be interpreted as "*within* ______ yds of the buoy's Assigned Position 90% of the time."

3. Select baseline data, mean and standard deviation, from the SRA Design Manual for each region and apply relevant corrections for ship size and channel width as directed in Section 5 of the Manual. The corrected values, MN' and SD', should be available from a completed general-purpose analysis. If the Automated Relative Risk Factor software was used, these values appear in the report entitled "Component Calculations by Region."

4. To adjust each turn region for the effect of floating aids, select the most appropriate alternative from Table 22 for the subject current conditions. Figure 9 in Section 7.3.3 will assist the selection. Note that a displacement perpendicular to the channel edge for the turn buoys is assumed to be accompanied by an alongtrack displacement and the current forces responsible for the displacement. If conditions in the subject waterway are not comparable, the system designer must make a judgement that the experimentally-derived data either under-estimates or over-estimates risk for a region.

   Adjust MN' and SD' as instructed in Table 22. D was calculated in Step 2 here. Calculate B' for the crosstrack current component three ship lengths past the turn apex as follows:

   B' (feet) = (length/2) x (crosstrack current/transit speed) + (beam/2)

   Note that the calculation of actual B' will provide the most sensitive adjustments of RRF to conditions. As an approximation, a value may be selected from the Design Manual, Table 5.3, page 5-60 or

TABLE 22. ADJUSTING DESIGN MANUAL DATA IN TURN REGION

FOLLOWING TO CROSSCURRENT: Current to Outside at Pullout, Buoys Late and to Outside MN: (MN') + (0.46 x |D|) SD: (SD') + (0.27 x |D|) B': adjust for crosscurrent	HEAD TO CROSSCURRENT: Current to Inside at Pullout, Buoys Early and to Inside MN: (MN') -(0.46 x |D|) SD: (SD') +(0.27 x |D|) B': adjust for crosscurrent
CROSS- TO FOLLOWING CURRENT: current following in pullout, buoys late MN: (MN') + (0.46 x |D|) SD: (SD') + (0.27 x |D|) B': beam/2	CROSS- TO HEAD CURRENT: head current in pullout, buoys early MN: (MN') -(0.46 x |D|) SD: (SD') B': beam/2

NOTES:

MN': from Design Manual with relevant corrections. (See page 5-30)

SD': from Design Manual with relevant corrections. (See page 5-30)

B': (length/2)x(crosstrack current/transit speed) + (beam/2)

or see Design Manual, Page 5-28

D: distance of buoys perpendicular to channel edge in pullout leg:

sin θ x distance from assigned position.

where θ = current direction - channel heading in pullout leg.

B' can be taken from the software report entitled "Component Calculations by Region." The method used should be consistent.

Calculate the RRF value as in the Design Manual, Section 5. As a reminder:

[(W/2)-(MN')-(B')] / (SD') = (NS)
[(W/2)+(MN')-(B')] / (SD') = (NP)

A table of values showing the area of the normal curve falling beyond N is required. One appears in the SRA Design Manual.

(PS)+(PP) = (RRF)

Sample calculations appear in Table 23. At the top of the table is baseline data for a noncutoff, 35 degree, three-buoy turn, for daytime conditions. Assume no corrections are necessary for ship size or channel width and that the perpendicular distance of the buoys from the channel edge is 69 feet. Calculations are shown for all four current alternatives. The relationships among the baseline and four current alternatives may be compared to the experimental performance data presented in the present report in Section 6, Table 18.

5. To adjust each recovery region for the effect of floating aids, select the most appropriate alternative in Table 24 and follow the instructions for calculating the RRF.

6. To adjust each trackkeeping region for the effect of floating aids, select the most appropriate alternative in Table 25 and follow the instructions for calculating the RRF.

7. Arrange all calculated values in order by region for the transit. If the objective of the analysis requires calculation of RRF values for another set of conditions (for example, a change of current) arrange those along side for easy comparison. Consider the SRA Design Manual, Section 9 for further uses of the results.

TABLE 23. SAMPLE ADJUSTMENTS OF DESIGN MANUAL DATA FOR TURN REGION

Step 1: All four channel/current orientations shown in Figure 9 are of interest.

Step 2: Perpendicular distance of buoys:

θ = current direction - channel heading in pullout leg
$\theta = 341^{\circ}T - 306^{\circ}T$
$= 35^{\circ}$

D = sin θ x distance from assigned position
D = sin 35° x 120 feet
D = 69 feet

Step 3: Select baseline data from manual.
Assume no corrections for ship size and channel width are necessary:

DESIGN MANUAL (Page 5-4)
NON-CUTOFF, 20 Degrees, Day, 3 Buoys

MN:	65
SD:	33
B':	67
RRF:	0.002

Step 4: Adjust for effects of floating buoys B'. Values are taken from Manual, Table 5.3, page 5-60.

FOLLOWING TO CROSSCURRENT:

MN: (65) + (0.46 x 69) = 97
SD: (33) + (0.27 x 69) = 52
B': (67)
RRF: [(500/2) -(97) -(67)] /(52) = 1.65
[(500/2) +(97) -(67)] /(52) = 5.38
RRF = 0.0495

HEAD TO CROSSCURRENT:

MN: (65) - (0.46 x 69) = 33
SD: (33) + (0.27 x 69) = 52
B': (67)
RRF: [(500/2) -(33) -(67)] /(52) = 2.88
[(500/2) +(33) -(67)] /(52) = 4.15
RRF = 0.0020

CROSS- TO FOLLOWING CURRENT

MN: (65) + (0.46 x 69) = 97
SD: (33) + (0.27 x 69) = 52
B': (42.5)
RRF: [(500/2) -(97) -(42.5)] /(52) = 2.12
[(500/2) +(97) -(67)] /(52) = 5.85
RRF = 0.0170

CROSS- TO HEAD CURRENT

MN: (65) - (0.46 x 69) = 33
SD: (33)
B': (42.5)
RRF: [(500/2) -(33) -(42.5)] /(52) = 3.36
[(500/2) +(33) -(42.5)] /(52) = 4.62
RRF = 0.0004

TABLE 24. ADJUSTING DESIGN MANUAL DATA IN THE RECOVERY REGION

CROSSCURRENT TO OUTSIDE: Buoys to Outside MN: (MN') + (0.17 x|D|) SD: (SD') + (0.35 x|D|) B': adjust for crosscurrent	CROSSCURRENT TO INSIDE: Buoys to Inside MN: (-MN') -(0.17 x|D|) SD: (SD') B': adjust for crosscurrent
FOLLOWING CURRENT: Buoys Late MN: (MN') SD: (SD') B': beam/2	HEAD CURRENT: Buoys Early MN: (KMN') SD: (SD') B': beam/2

NOTES:

MN': from Design Manual with relevant corrections. (See page 5-62)

SD': from Design Manual with relevant corrections. (See page 5-62)

B': (length/2)x(crosstrack current/transit speed) + (beam/2)

or see Design Manual, Page 5-28

D: distance of buoys perpendicular to channel edge:

sin θ x distance from assigned position.

where θ = current direction - channel heading.

KMN': value taken from Design Manual for Trackkeeping region with relevant corrections. (See page 5-71)

TABLE 25. ADJUSTING DESIGN MANUAL DATA IN THE TRACKKEEPING REGION

CROSSCURRENT TO STARBOARD: Buoys to Starboard MN: (MN') + (0.75 x $\|D\|$) SD: (SD') B': adjust for crosscurrent	CROSSCURRENT TO PORT: Buoys to Port MN: (-MN') -(0.75 x $\|D\|$) SD: (SD') B': adjust for crosscurrent
FOLLOWING CURRENT: Buoys Late Repeat Recovery Region Performance	HEAD CURRENT: Buoys Early Repeat Recovery Region Performance

NOTES:

MN': from Design Manual with relevant corrections. (See page 5-71)

SD': from Design Manual with relevant corrections. (See page 5-71)

B': (length/2)x(crosstrack current/transit speed) + (beam/2)

or see Design Manual, Page 5-28

D: distance of buoys perpendicular to channel edge:

sin θ x distance from assigned position.

where θ = current direction - channel heading.

Appendix A

MTRC SIMULATOR DESCRIPTION

Realistic simulation of the total *man-ship-environment* is a vital component in molding desirable behavior, for both maritime training and in analyzing human operator behavior in research applications. The Maritime Training and Research Center's full mission bridge simulator (See Figure A-1) provides this realistic simulation by means of the following components:

- Navigation Bridge - a full-scale, fully equipped wheelhouse (including radar) from which the simulation is controlled by the mariner (See Figure A-2)

- Control Station - a console from which simulator operators or instructors can start, monitor and terminate simulation exercises, and control other traffic ships, environmental conditions, or ship system failures

- Visual Scene - a large semi-circular screen surrounds the wheelhouse on which is projected a full color Computer Generated Image (CGI) that moves in real-time and displays surrounding geographic/cultural features, aids to navigation, and other traffic ships

- Host Computer - a digital computer which generates video signals to construct the CGI visual scene and required radar PPI information, stimulates various repeaters/indicators on the bridge, and controls the motion of ownship in accordance with its equations of motion

- Classroom - an area utilized by trainees and instructors for a number of functions including formal lectures, presentations of audio/visual material, exercise planning, briefing, monitoring, and postexercise critique

- Monitoring Station - a remote monitoring location with capabilities which permit trainees to learn from observing the performance of others on the simulator. These features include audio and visual monitoring of persons on the simulator bridge, monitors which display the radar PPI and visual scene as observed in the wheelhouse, and communications equipment

- Graphic Feedback Display - a large screen projection system with a variety of computer graphic applications used in the playback of recorded exercise data to reinforce the on-bridge training. Ship control parameters, such as rudder angle and engine RPM, and the actual track of the simulator ownship, can be presented to trainees in graphic format for postexercise critique of their individual performance

Operation of the various control equipment provides inputs to the Host Computer which then directs the visual and radar generation subsystems to display apparent motion as described previously. The computer also drives the various indicators on the bridge to display information showing the

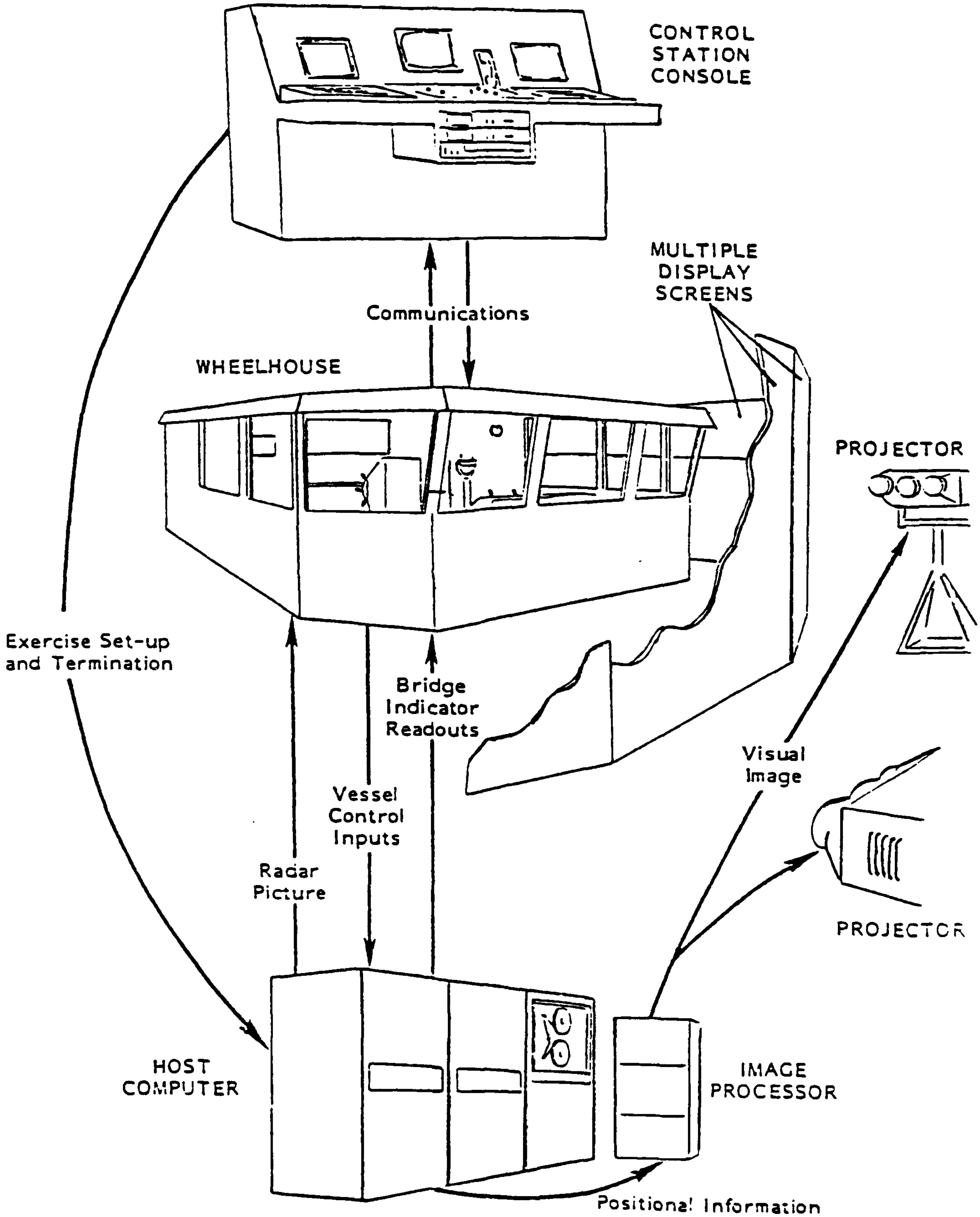
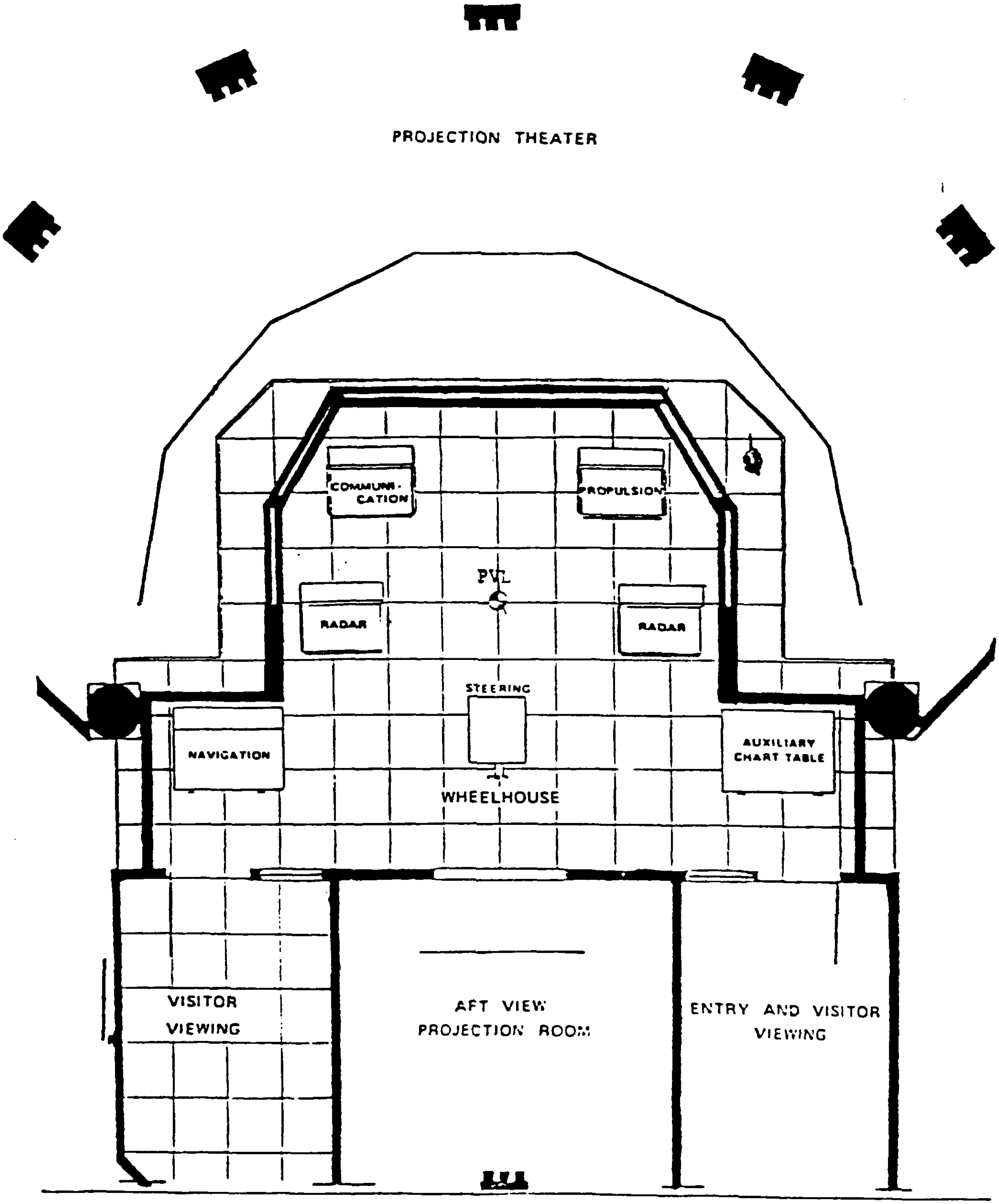


Figure A-1: Bridge Simulator Components



NOTE: PVL - Preferred Viewing Location

Figure A-2: Wheelhouse Arrangement - Plan View

result of control actions, for example, readings of the speed log, RPM and rudder angle indicators.

a. Steering Stand - includes rudder order, rudder angle (position) indicator, ship's wheel, steering mode selector, (manual, gyro and NFU modes of steering), gyro steering controls, gyrocompass repeater, and yaw rate indictor.

b. Propulsion Controls - includes engine orders telegraphs, propeller shaft RPM indicators, propeller pitch indicators and handle control units for twin or single screw operation.

c. Bow Thruster Control - direction and thrust magnitude command, motor amperes indicator.

d. Anchor Control - simulates the operation of the anchor windlass and permits the deployment of a bow anchor during vessel maneuvers. A control selector and anchor chain indicator (displaying the number of shots deployed) is provided.

e. Speed Log - provides a digital readout of the vessel's forward or aft speed. A selector permits either over-the-ground or through-the-water speed readouts.

f. Fathometer - displays a digital readout of under keel clearance in either feet or fathoms dependent upon selector position.

g. Gyrocompass Repeater Stand - a floor mounted pedestal fitted with a pelorus ring situated in the center of the wheelhouse for the purpose of taking visual bearings to objects in the visual scene.

h. Radio Direction Finder - an RDF unit with selector switch for obtaining radio bearings from up to four predesigned radio beacons.

i. LORAN C Receiver - displays a digital readout of latitude and longitude.

j. Bridge Clock - two digital clocks, one for a forward bridge console and the other at the navigation station. They are automatically set and will run with the simulation exercise.

k. Communication Equipment - a multi-channel VHF radio telephone transceiver, two intercom units (at the bridge console and navigation station) and ownship's whistle control. The intercom units are used for intra-ship communications such as with the forecastle, engine room, lookout, etc.

l. Overhead Mounted Indicators - includes indicators showing apparent wind speed and direction mounted over the forward windows, as well as repeaters of the rudder angle indicator and shaft RPM indicators.

Appendix B

PILOT BRIEFING PACKAGE

INTRODUCTION

The experiment is designed to investigate the effects of buoy position on the piloting process. You will be asked to make a number of transits, each with the same 30,000 dwt tanker through the same channel. In some transits the buoys will be fixed at their exact charted positions. In other transits they will be floating and displaced, as if to the limit of their watch circles, by wind and current

When the buoys are floating, both the distance and the direction of displacement are of interest and both will change between transits. The buoys will change in distance of displacement, assuming different sizes of watch circles. The direction of the displacement will change to correspond to the wind and current acting on the ship during a transit.

In practice, a pilot has information on which to base a judgment of a floating buoy's position relative to its charted position. He may be familiar with the relationships between buoys and fixed objects adjacent to the waterway, or he may infer the displacement of the buoy based on his knowledge of the state of the current, the depth of the water, etc. In this experiment you will be transiting a fictional waterway; you will have no "local knowledge" that would allow you to judge the positions of the buoys. Before each transit the experimenter will provide you with not only the direction of the current, but also its probable effect on the positions of the buoys. Thus, we will attempt to provide you with information similar to that which you would normally possess as a result of your experience and observations.

THE CHANNEL FOR ALL SCENARIOS

The channel is 500 feet wide with a single 35-degree turn to the left. There are no bank effects. The channel's depth will provide sufficient under keel clearance to the ship.

All transits will be run in the daytime and with sufficient visibility to see twice the spacing of the buoys.

The chart for the familiarization scenario is attached as Figure 1 to illustrate the channel. But note that some of the conditions will change for later scenarios. The experimenter will provide you with a chart and a description of conditions before each scenario.

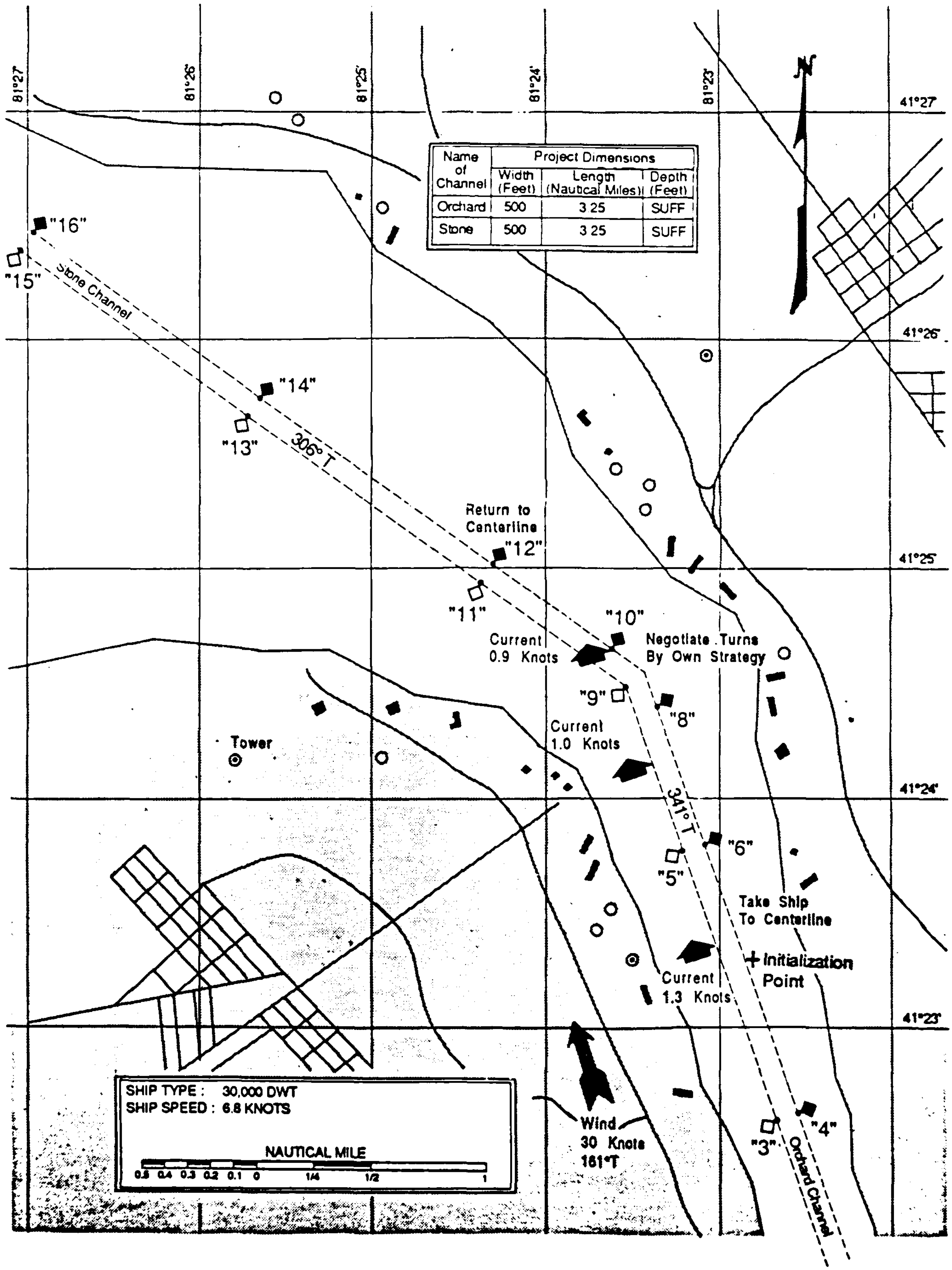


Figure 1: Familiarization Scenario

SHIP PARTICULARS

The ship is a 30,000 dead weight ton (dwt) tanker, that is fully loaded with a draft of 35 feet, a length of 595 feet at the waterline and a beam of 84 feet. The maneuvering characteristics are attached as Figures 2A and 2B.

The ship has a split house with the bridge 85 feet forward of the center of gravity. The eyepoint is 48 feet above the water. The location of the eyepoint along the ship's axis is illustrated in Figure 3.

The EOT, RPM, speed equivalents are as follows:

EOT	RPM	SPEED (KTS)
DEAD SLOW AHEAD	11	1.7
SLOW AHEAD	22	3.4
HALF AHEAD	44	6.8
FULL AHEAD	88	13.6

BRIDGE LAYOUT AND EQUIPMENT

The bridge is laid out like a typical merchant bridge. There will be a helmsman to receive your orders. You will operate the EOT. Please announce your changes.

Radar will be available for the familiarization scenario. This is an evaluation of visual environment and there will be no radar available for the other experimental scenarios. There will be a gyrocompass repeater with bearing ring, a rudder angle indicator, RPM indicator, speed log and ships clock. The preferred viewing location is at the center gyro repeater.

TURN CIRCLE DATA   FULL AHEAD -35 DEG RUDDER

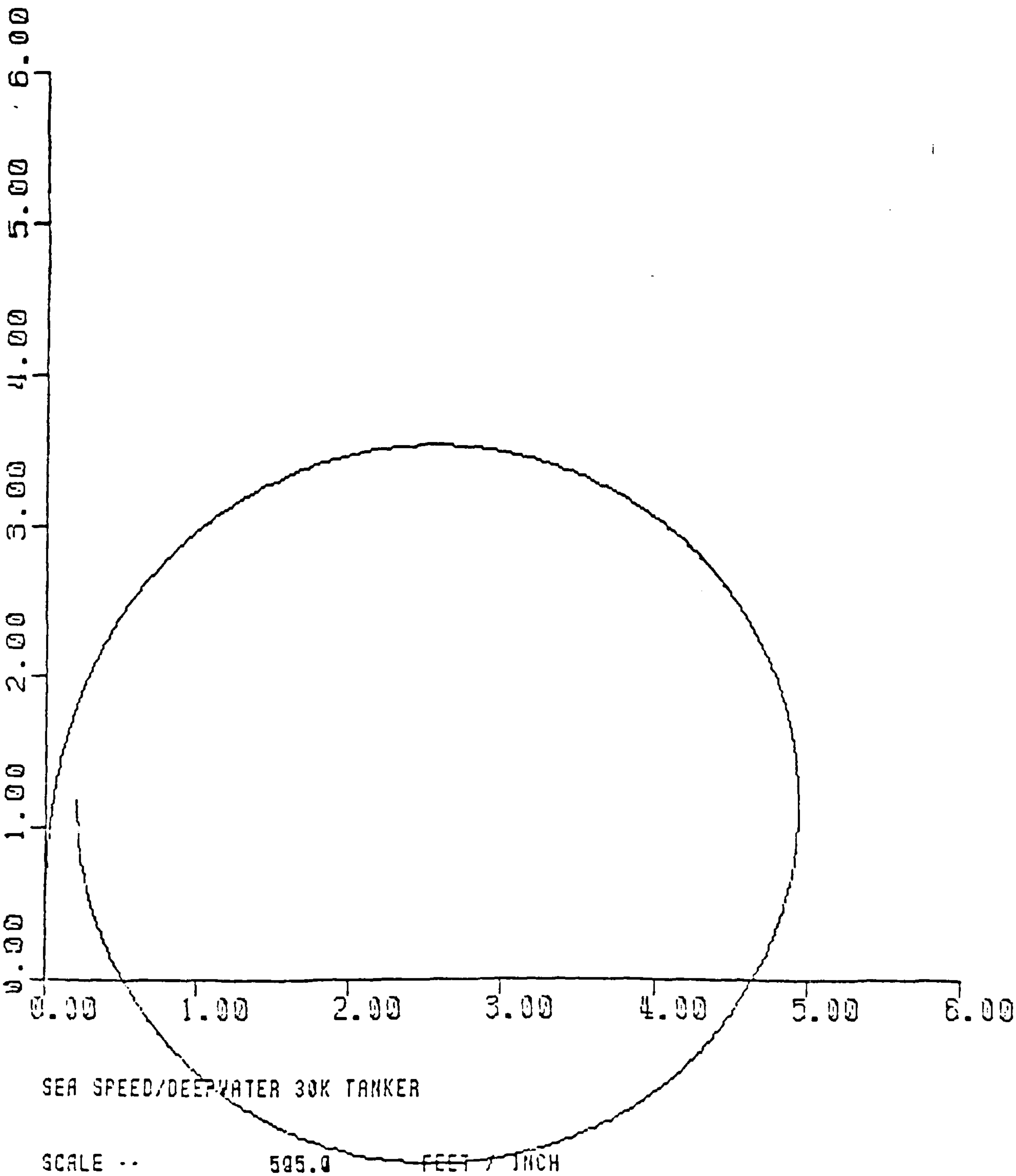


Figure B-2A

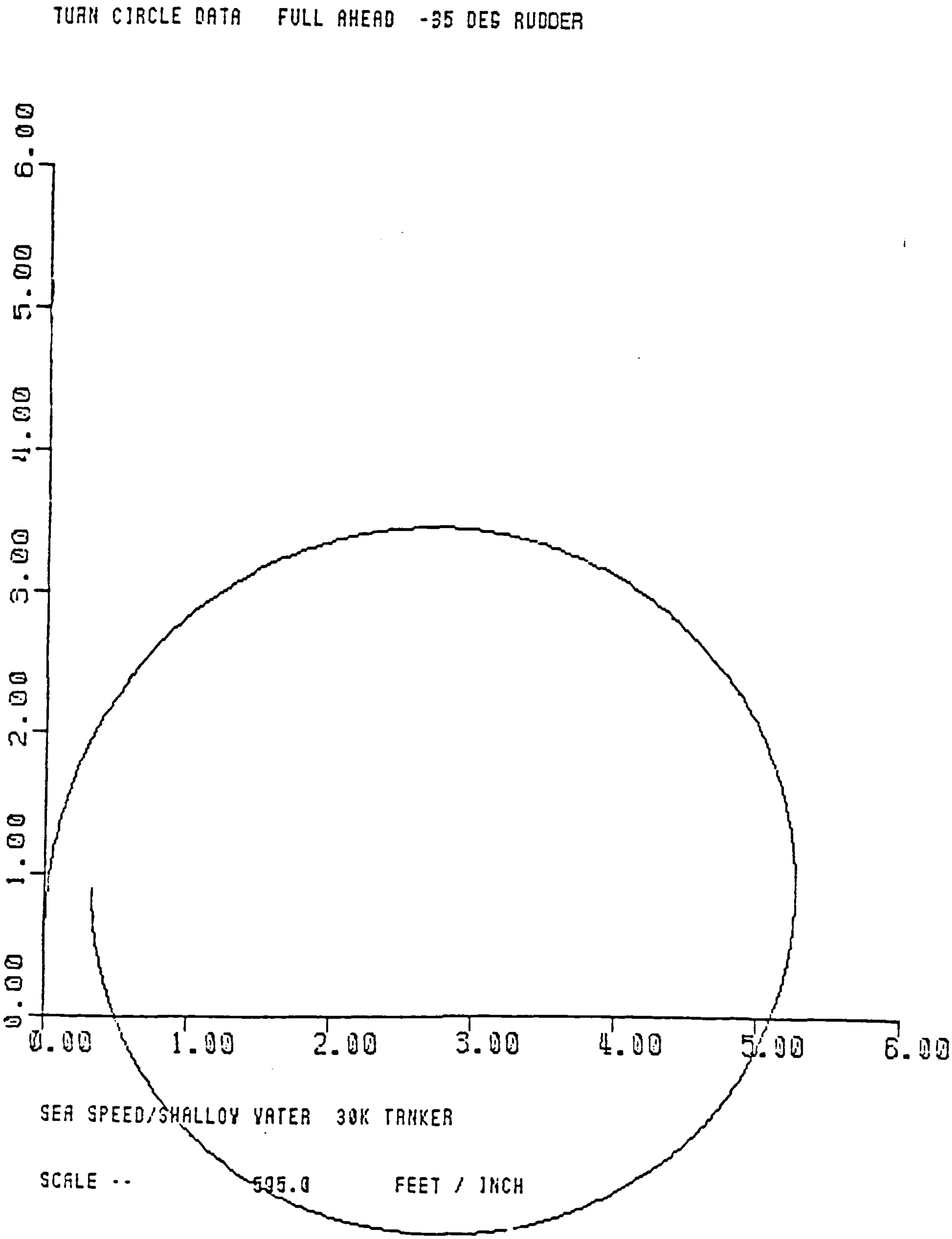

TURN CIRCLE DATA FULL AHEAD -35 DEG RUDDER
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
SEA SPEED/SHALLOW WATER 30K TANKER
SCALE -- 595.0 FEET / INCH

Figure B-2B

Length - Overall	616 ft
Length - Between Perpendiculars	595 ft
Beam	84 ft
Draft	35 ft
Eyepoint - Above Water	48 ft
Eyepoint - Forward of Center of Gravity	85 ft

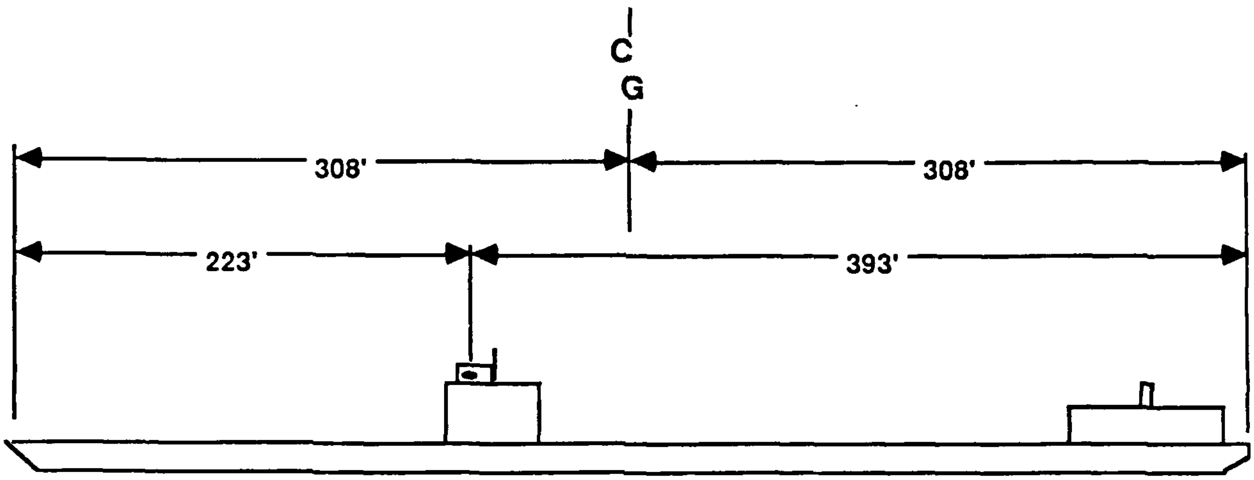


Figure 3 : 30,000 DWT Tanker

CONDITIONS AND INSTRUCTIONS FOR FAMILIARIZATION

A shoreline will be visible and the radar available for the familiarization scenario only.

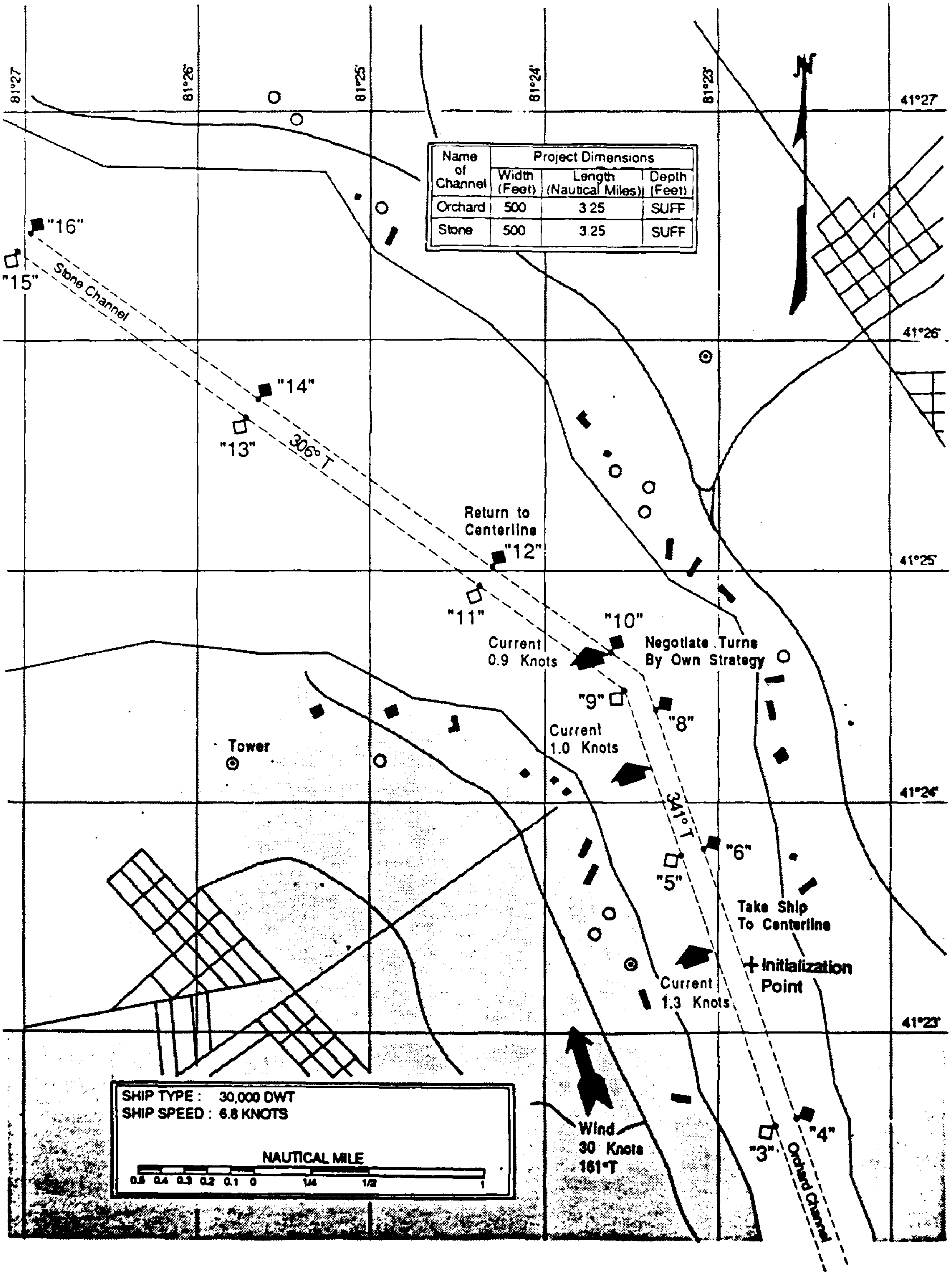
The current direction will be to 341°T throughout the scenario. That is, following in the first leg and from broad on the port quarter in Leg 2. The current speed will be at 1.3 knots at the start and will decrease throughout the scenario as shown on figure for the scenario. It will be zero as the scenario ends.

The wind will be from 161°T with some small variation in direction. It will be gusting up to 30 knots.

For the familiarization scenario only, the scenario will start with the ship just outside the channel at the position indicated on the attached chart. The necessity to maneuver into the channel is meant to help familiarize you with the ship. All subsequent scenarios will begin inside the channel.

At the start of the scenario ownship's speed through the water will be approximately 6.8 knots. Take the ship to the centerline of the channel as quickly as you think prudent. Please stay as close to a strictly defined "centerline" as is practical. You may leave the centerline when necessary to set up for the turn. You will be free to use the EOT to increase RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible after the turn, announcing that change as well. Negotiate the turn by your own technique, and return to the centerline as quickly as possible in the next leg.

When you feel that you are sufficiently familiar with the ship and the effects of the current, please ask the operator to end the scenario.



Name of Channel	Project Dimensions		
	Width (Feet)	Length (Nautical Miles)	Depth (Feet)
Orchard	500	3.25	SUFF
Stone	500	3.25	SUFF

Figure 1: Familiarization Scenario

CONDITIONS AND INSTRUCTIONS FOR SCENARIOS 1 AND 2

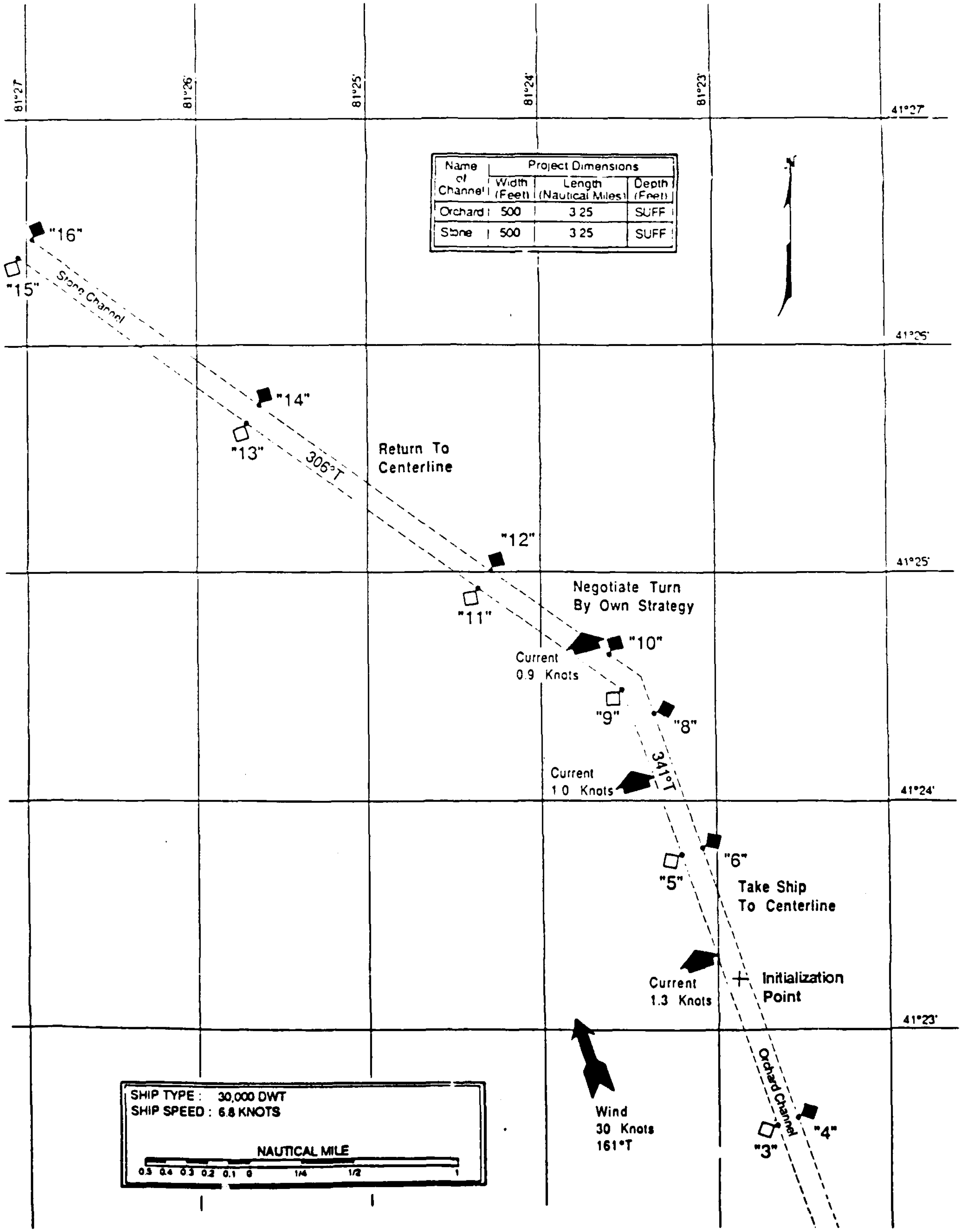
For both Scenarios 1 and 2 the buoys are fixed at their exact charted location and are unaffected by wind and current. These scenarios differ only in the number and arrangement of the buoys.

The current direction will be to 341°T throughout the scenario. That is, following in the first leg and from broad on the port quarter in Leg 2. The current speed will be at 1.3 knots at the start and will decrease throughout the scenario as shown on figure for the scenario. It will be zero as the scenario ends.

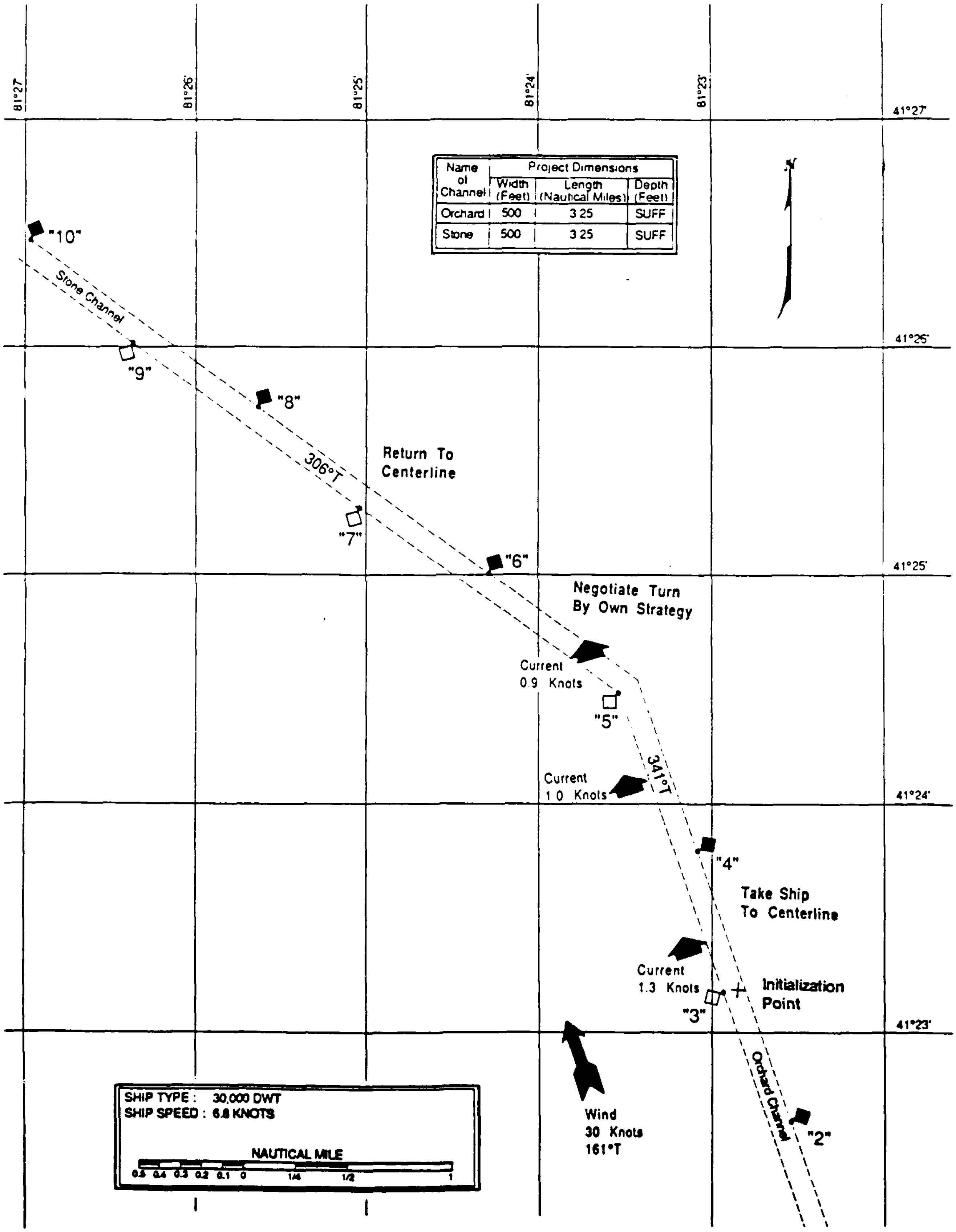
The wind will be from 161°T with some small variation in direction. It will be gusting up to 30 knots.

The scenario will start with the ship 100 feet from the centerline of the channel, approximately 1-1/3 nautical miles below the turn, as indicated on the figure.

At the start of the scenario ownship's speed through the water will be approximately 6.8 knots. Take the ship to the centerline of the channel as quickly as you think prudent. Please stay as close to a strictly defined "centerline" as is practical. You may leave the centerline when necessary to set up for the turn. You will be free to use the EOT to increase RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible after the turn, announcing that change as well. Negotiate the turn by your own technique, and return to the centerline as quickly as possible in the next leg.



Scenario 1, Fixed Aids, Decreasing Currents



Scenario 2, Fixed Aids, Decreasing Currents

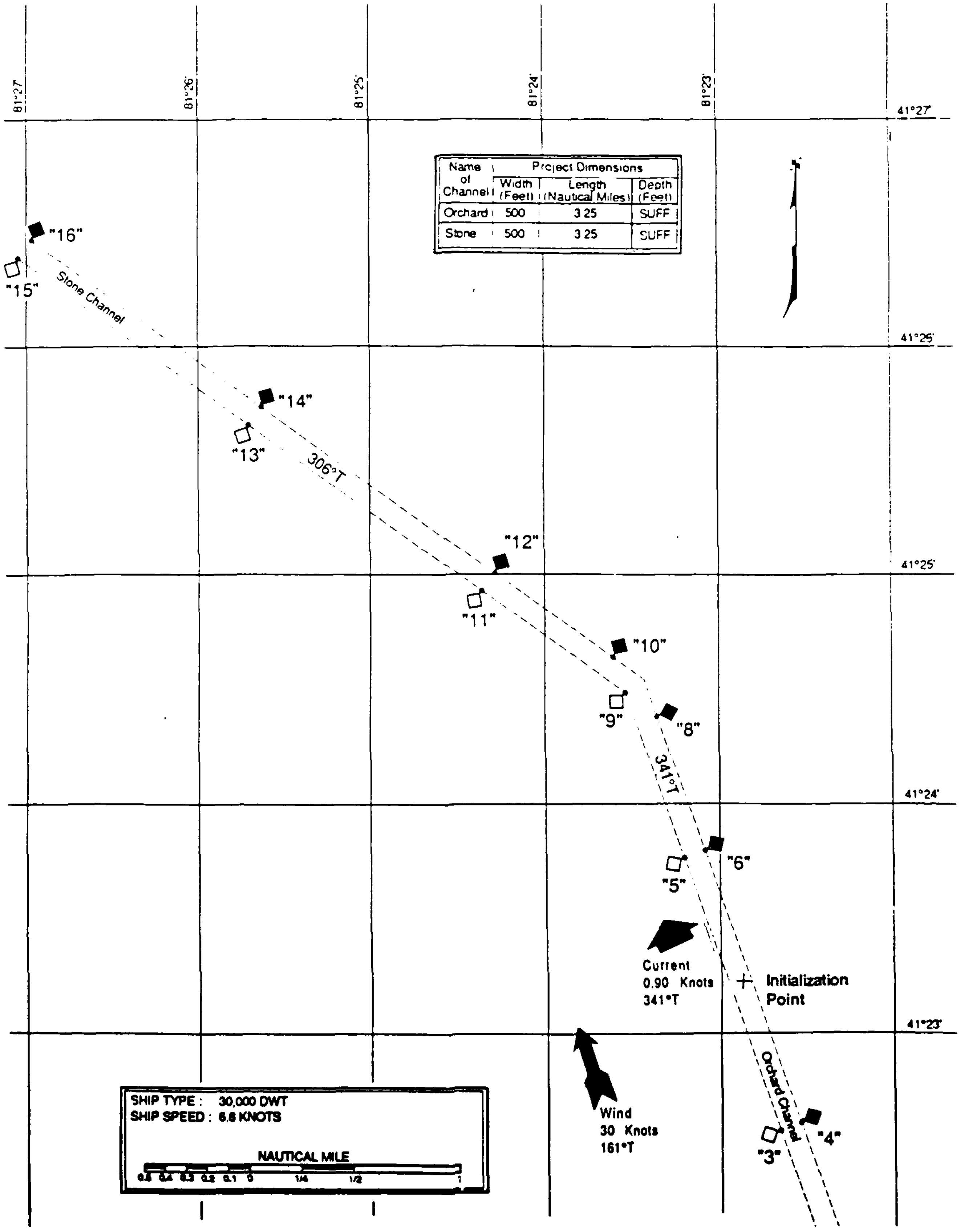
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 3

In Scenario 3 the buoys *are up to 24 yards, or 72 feet, from their* charted locations. The direction of the displacement is determined by the current and wind.

The current is to 341°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 161°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to the centerline of the dredged channel or to an appropriate track in the next leg. Continue until the end of the scenario.



Name of Channel	Project Dimensions Width (Feet)	Length (Nautical Miles)	Depth (Feet)
Orchard	500	3 25	SUFF
Stone	500	3 25	SUFF

Scenario 3, 24 Yards or 72 Feet

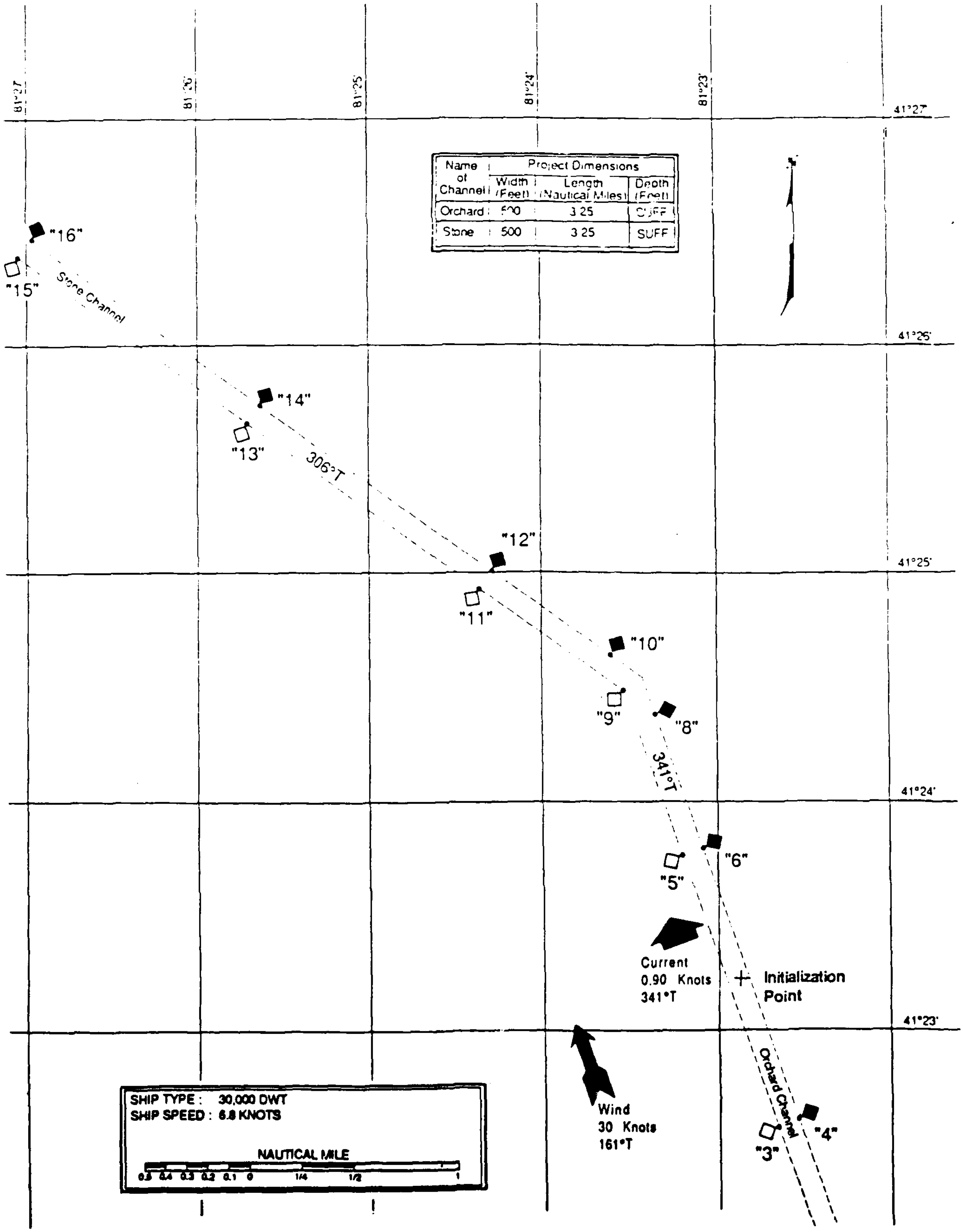
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 4

In Scenario 4 the buoys are up to 40 yards, or 120 feet, from their charted locations. The direction of the displacement is determined by the current and wind.

The current is to 341°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 161°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to the centerline of the dredged channel or to an appropriate track in the next leg. Continue until the end of the scenario.



Scenario 4, 40 Yards or 120 Feet

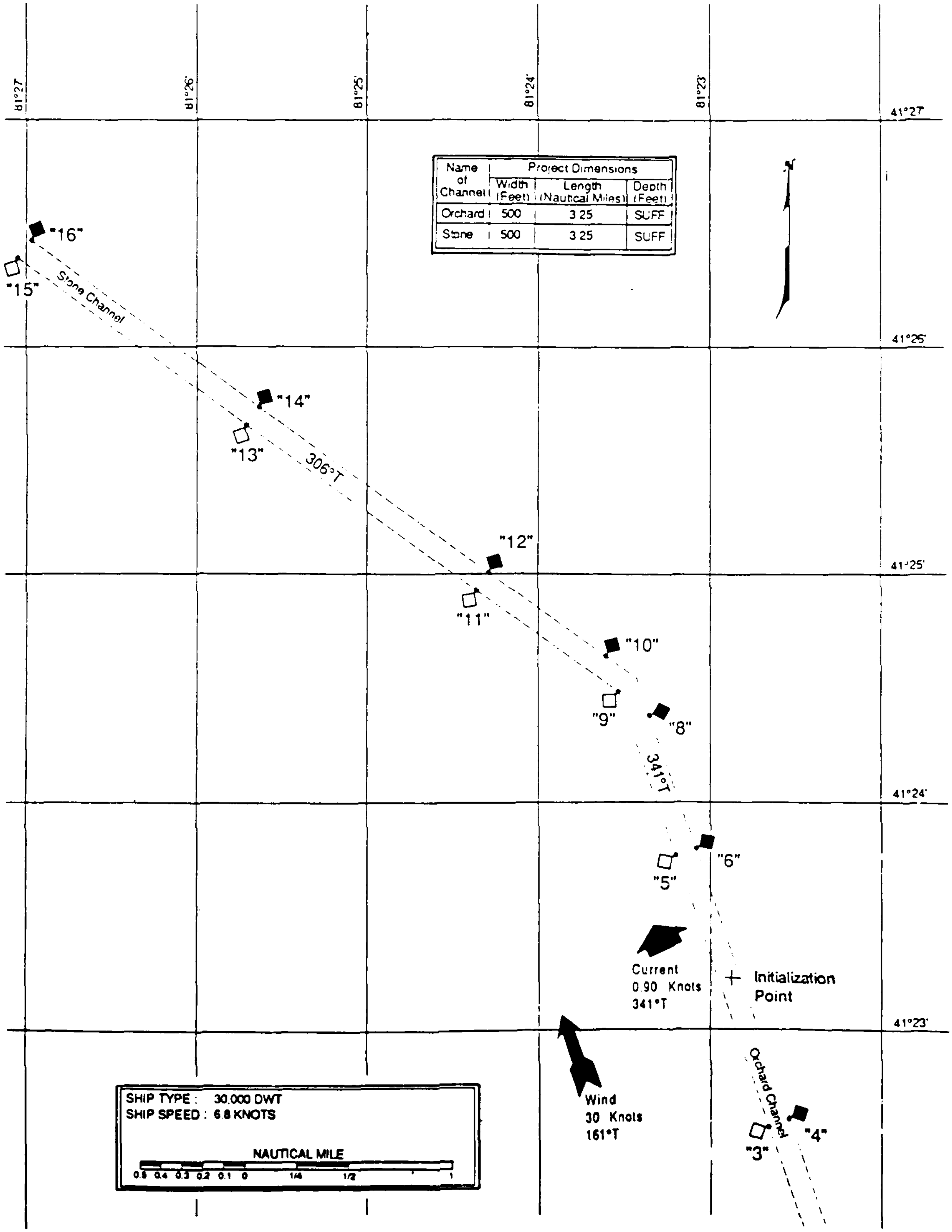
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 5

In Scenario 5 the buoys are up to 60 yards, or 180 feet, from their charted locations. The direction of the displacement is determined by the current and wind.

The current is to 341°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 161°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to the centerline of the dredged channel or to an appropriate track in the next leg. Continue until the end of the scenario.



Name of Channel	Project Dimensions		
	Width (Feet)	Length (Nautical Miles)	Depth (Feet)
Orchard	500	3.25	SUFF
Stone	500	3.25	SUFF

Scenario 5, 60 Yards or 180 Feet

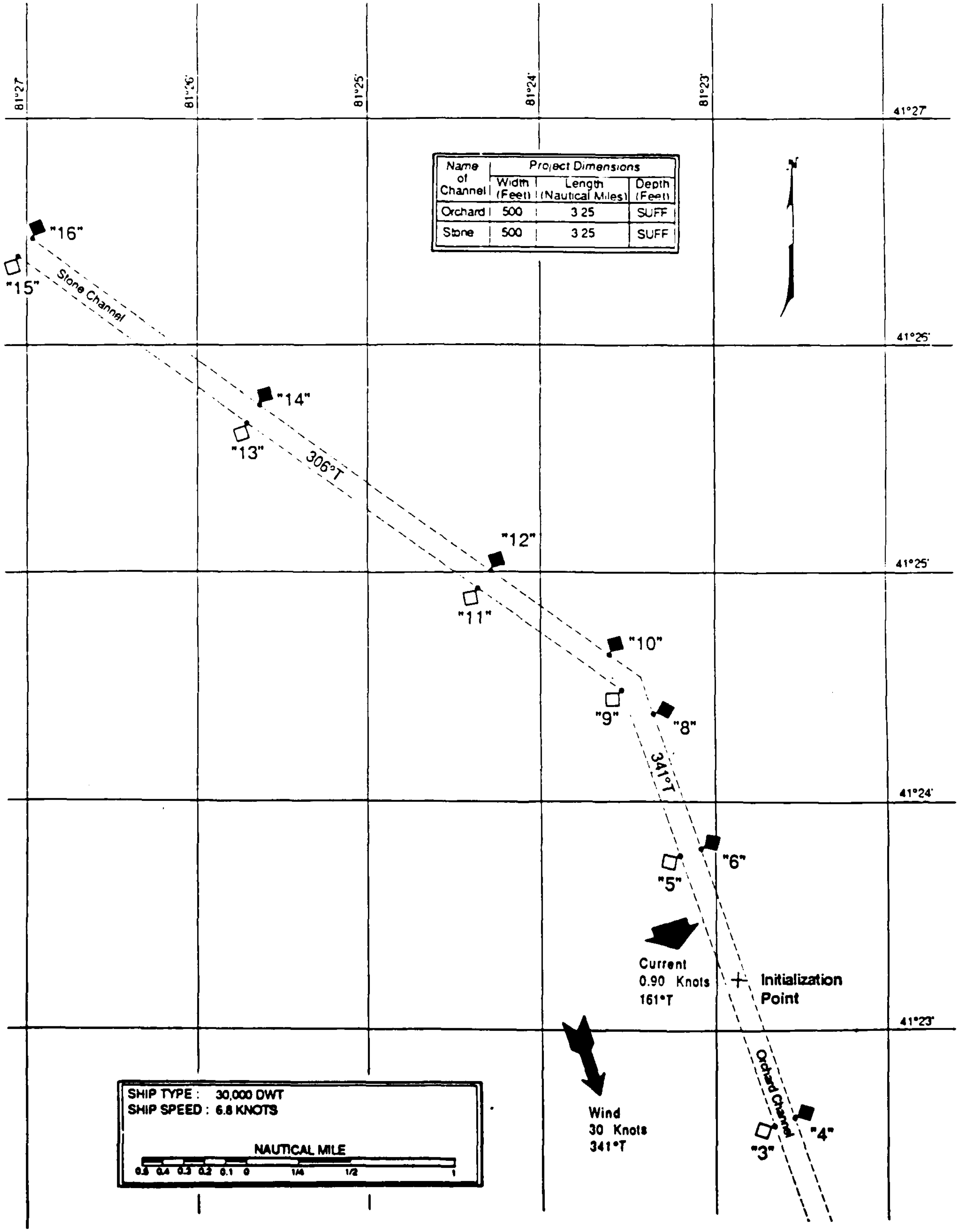
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 6

In Scenario 6 the buoys are up to 40 yards, or 120 feet, from their charted locations. The direction of the displacement is determined by the current and wind.

The current is to 161°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 341°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to the centerline of the dredged channel or to an appropriate track in the next leg. Continue until the end of the scenario.



Scenario 6, 40 Yards or 120 Feet

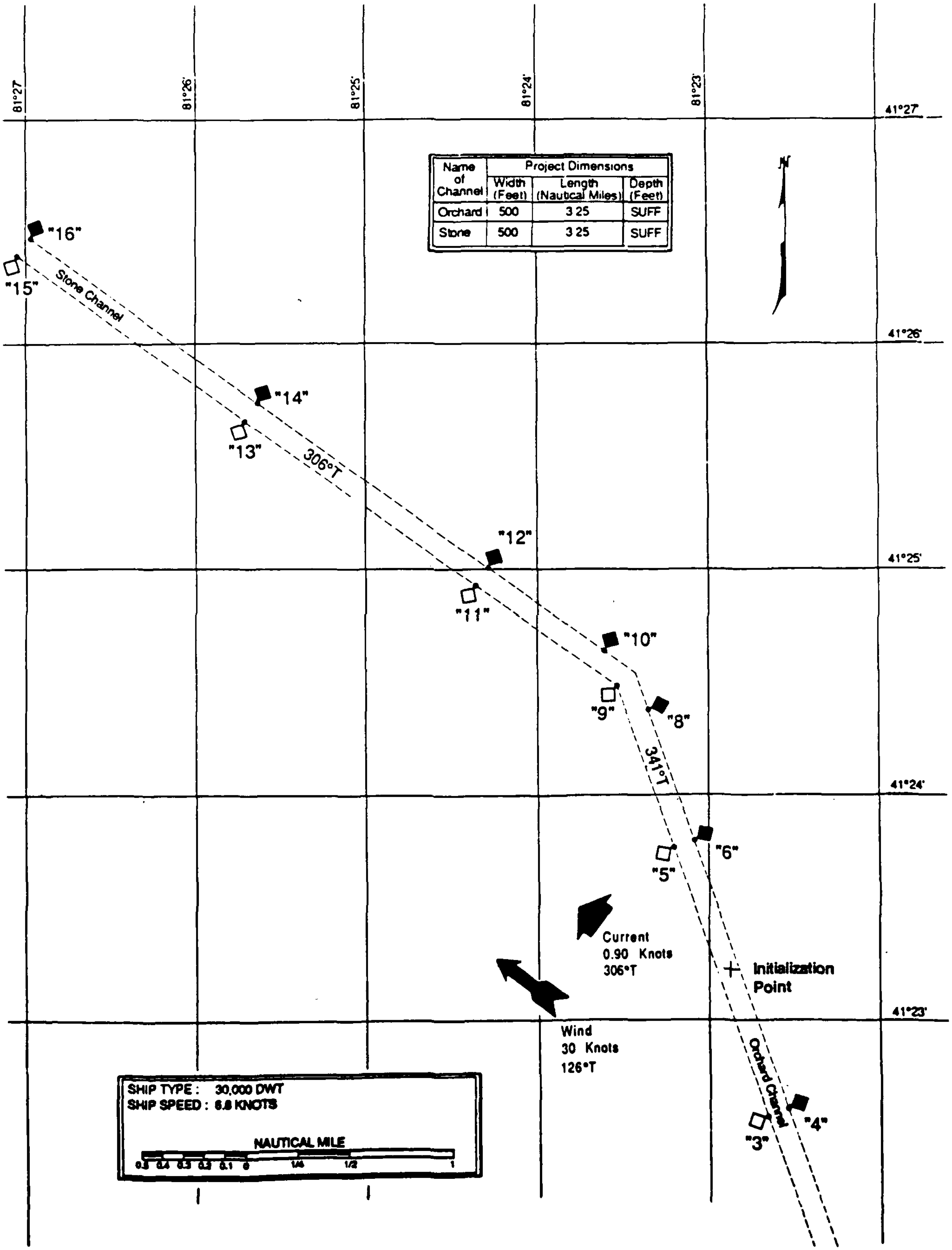
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 7

In Scenario 7 the buoys are up to 40 yards, or 120 feet, from their charted locations. The direction of the displacement is determined by the current and wind.

The current is to 306°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 126°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to the centerline of the dredged channel or to an appropriate track in the next leg. Continue until the end of the scenario.



Scenario 7, 40 Yards or 120 Feet

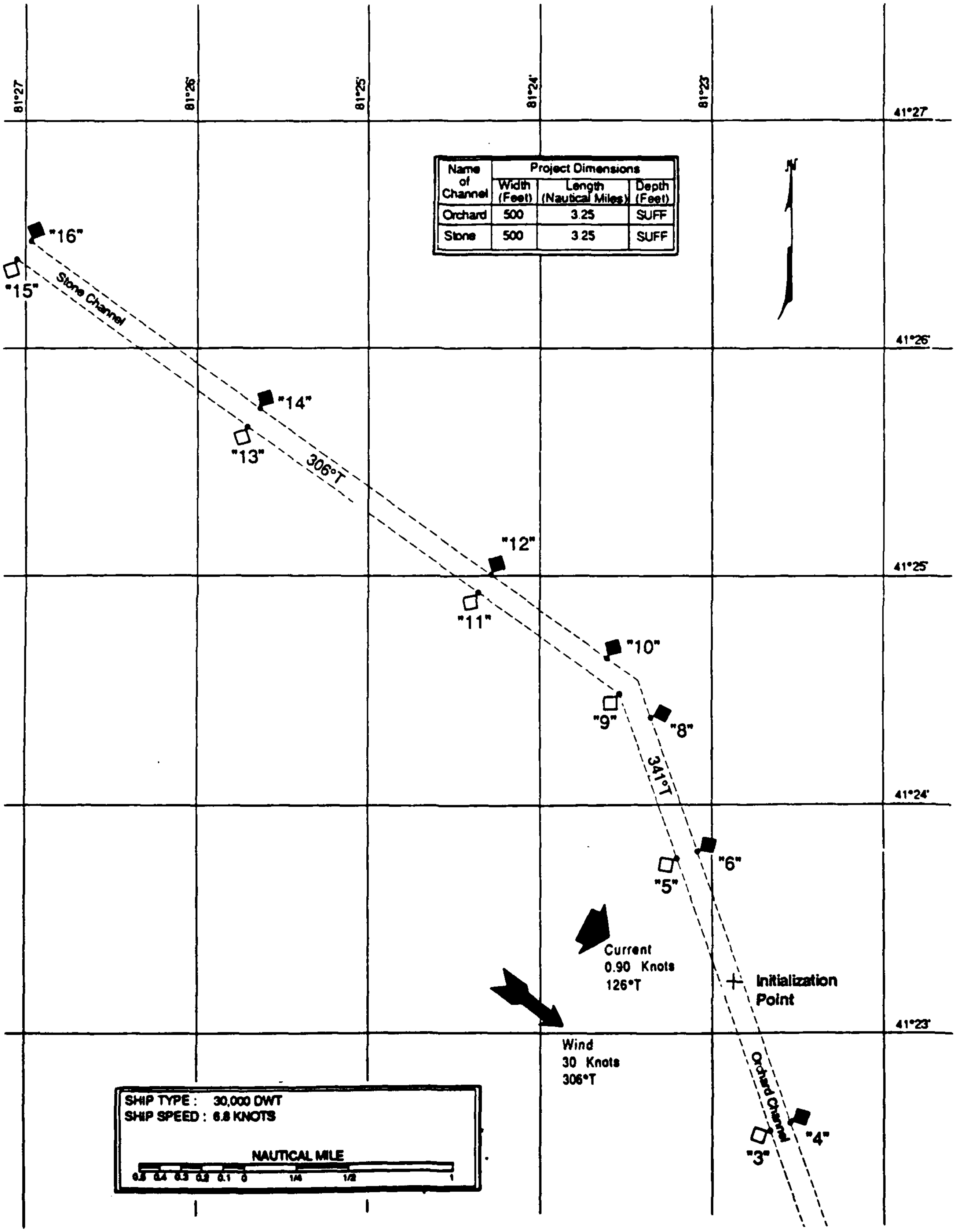
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 8

In Scenario 8 the buoys are up to 40 yards, or 120 feet, from their charted locations. The direction of the displacement is determined by the current and wind.

The current is to 126°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 306°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to the centerline of the dredged channel or to an appropriate track in the next leg. Continue until the end of the scenario.



Scenario 8, 40 Yards or 120 Feet

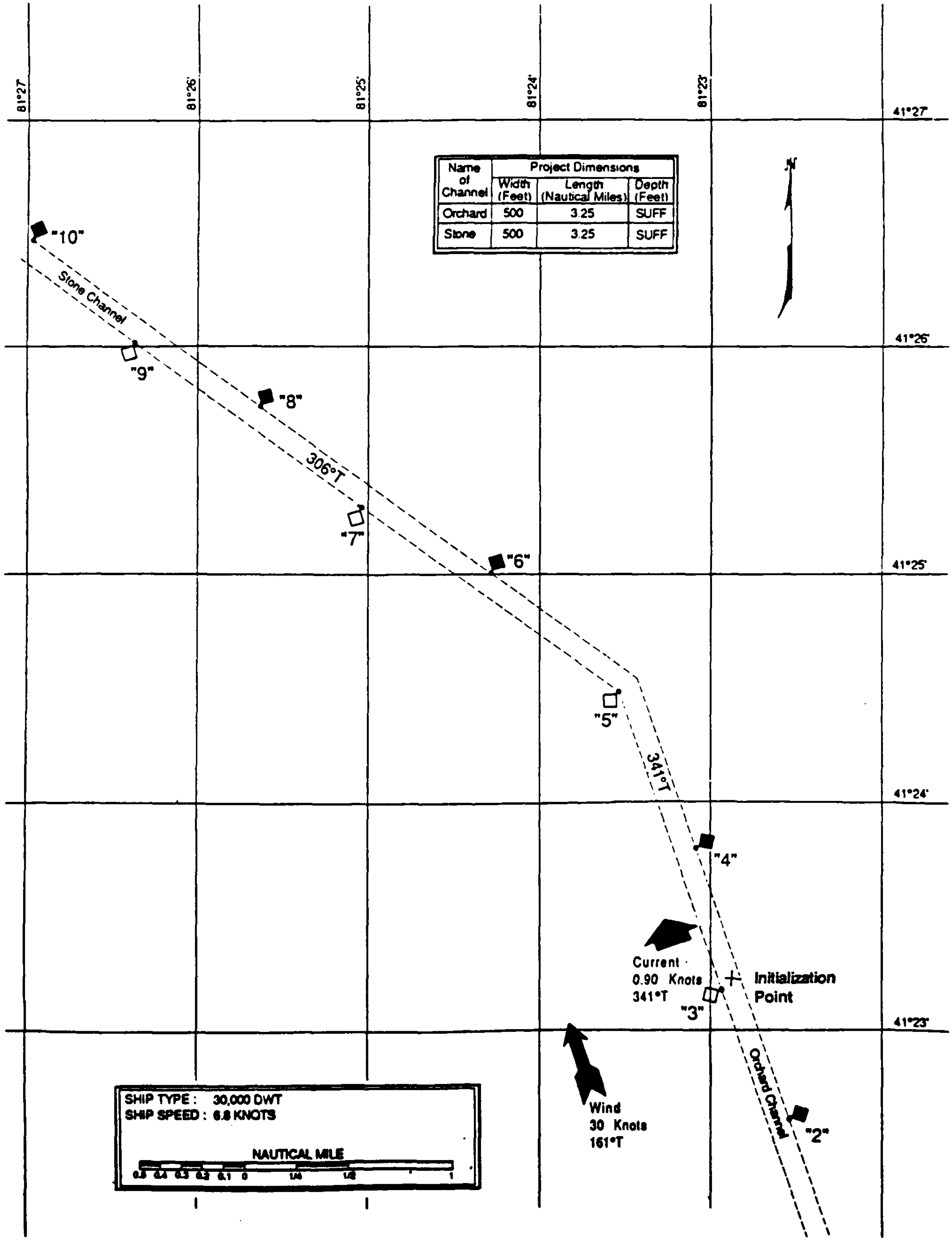
CONDITIONS AND INSTRUCTIONS FOR SCENARIO 9

In Scenario 9 the buoys are up to 40 yards, or 120 feet, from their charted locations. The direction of the displacement is determined by the current and wind.

The current is to 341°T and is a uniform 0.9 knots throughout the scenario.

The wind is from 161°T with some small variation in direction. It is gusting up to 30 knots.

The ship's speed at the start of the scenario will be approximately 6.8 knots through the water. Please take the ship to the centerline of the dredged channel or to a track you think is appropriate for conditions. Set up for the turn as you think appropriate. You may use the EOT to increase the RPM in the turn if you so desire. Please announce the change. Please return to the original 6.8 knots as soon as possible, announcing that change as well. Negotiate the turn by your own technique, and take the ship to an the centerline of the dredged channel or to appropriate track in the next leg. Continue until the end of the scenario.



Name of Channel	Project Dimensions		
	Width (Feet)	Length (Nautical Miles)	Depth (Feet)
Orchard	500	3.25	SUFF
Stone	500	3.25	SUFF

Scenario 9, 40 Yards or 72 Feet

Appendix C

PILOT DEBRIEFING QUESTIONNAIRE

QUESTIONS FOR THE FAMILIARIZATION RUN

1. Did the ship behave realistically as it was described?

   Was the bow realistic? The bridge wings? The bridge?

2. Did the wind and current behave realistically as described?

3. Was the familiarization scenario enough to familiarization you with the ship, current, wind, and channel?

   If not, what was needed?

4. How much did the centerline instructions and the slow speed contribute to the difficulty of the maneuvering needed for the transit?

5. Was the visual scene generally realistic?
   enough to help you in your transit?
   the buoys?
   objects?

PLEASE FEEL FREE TO CONTINUE TO COMMENT ON THESE MATTERS DURING THE DAY.

PILOT DEBRIEFING QUESTIONNAIRE

QUESTIONS FOR EACH SCENARIO

PILOT NAME____

SCENARIO NUMBER____

1a. Please describe the <u>piloting techniques</u> you used. How did you use the aids during your transit?

1b. Please compare the piloting techniques you used to those in the familiarization scenario or a recent scenario.

2a. What do you think the <u>ship track</u> looked like in this transit? Was it affected by the information regarding buoy displacement, the use you made of it, or the techniques you used?

2b. How do you think the ship tracks compare to those in the familiarization scenario or a recent scenario?

3a. How good was control of the ship during this transit? Could you have responded to traffic ships, emergencies, etc.?

3b. How did the control compare to that of the familiarization run or a recent scenario?

PILOT DEBRIEFING QUESTIONNAIRE

QUESTIONS FOR THE END OF THE DAY

1. In your experience, how far would you estimate channel buoys are displaced from their assigned positions under normal circumstances (i.e., what is the radius of the watch circle)?

2. In a channel with a moderate number of fixed reference points, how far must a buoy be displaced in order for it to be noticeable?

3. Do you evaluate a buoy's position by comparison to fixed objects, or estimate the amount of displacement based on the prevailing current and wind? Both? Neither?

4. Was the information you were provided regarding direction and distance of buoy displacement comparable to that you normally have based on "local knowledge"? How did it differ?

5. Do you usually adjust your ship's position relative to the buoys to compensate for anticipated displacement by current or wind?

6. In a channel similar to the one simulated in the experiment, how far must a buoy be displaced in order to cause you to adjust your position relative to the buoy?

7. In your experience do you encounter buoys displaced in the directions relative to the channels that were simulated? Which situation is most difficult in the real world? On the simulator?

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix D

SCENARIO PERFORMANCE, PLOTTED

The combined plots which follow (described in Section 4.2) are a graphic representation of the experimental runs from which the performance data in Section 5 were selected. They are arranged in numerical order by scenario. These conditions are summarized in Table D-1, which is repeated from the text as a convenience for the reader.

The format of the plots like that on page D-3 is identical to that employed in earlier experiments. The axis for the abscissa is scaled so that one unit of alongtrack distance represents 475 feet (5/64 nm). At a speed of 6.8 knots, the data lines 475 feet apart represent samples approximately every 40 seconds. The combined plot shows the crosstrack mean and an envelope encompassing two standard deviations to either side, an area within which performance is expected to occur 95 percent of the time.

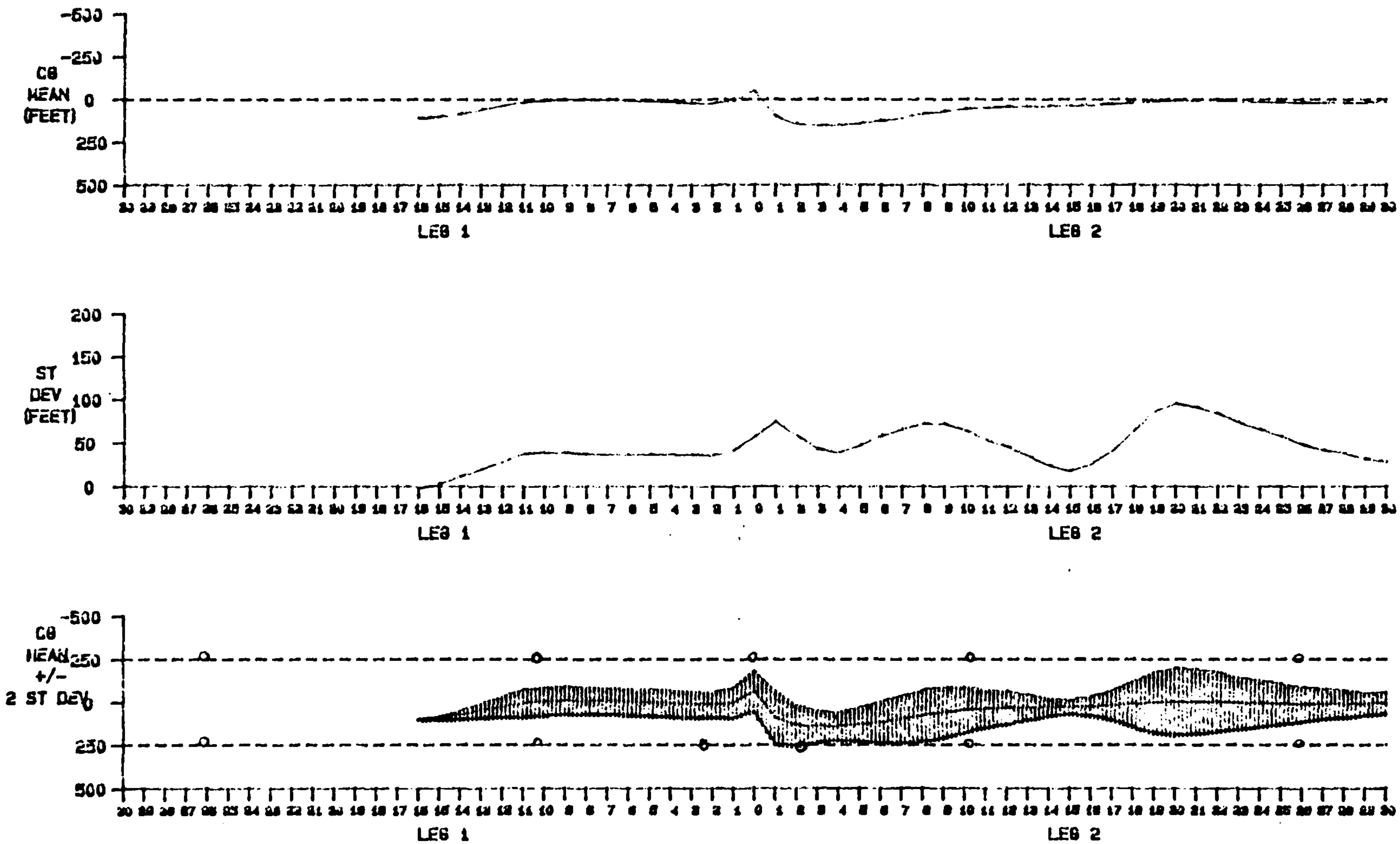
A second type of combined plot is illustrated by page D-4. This shows the same envelope through the 35-degree turn. Tick marks along the channel edge indicated the same data lines as in the straight axis plots. Note that this second combined plot shows only the turn, magnified to present a more effective graphical presentation of performances in this critical region.

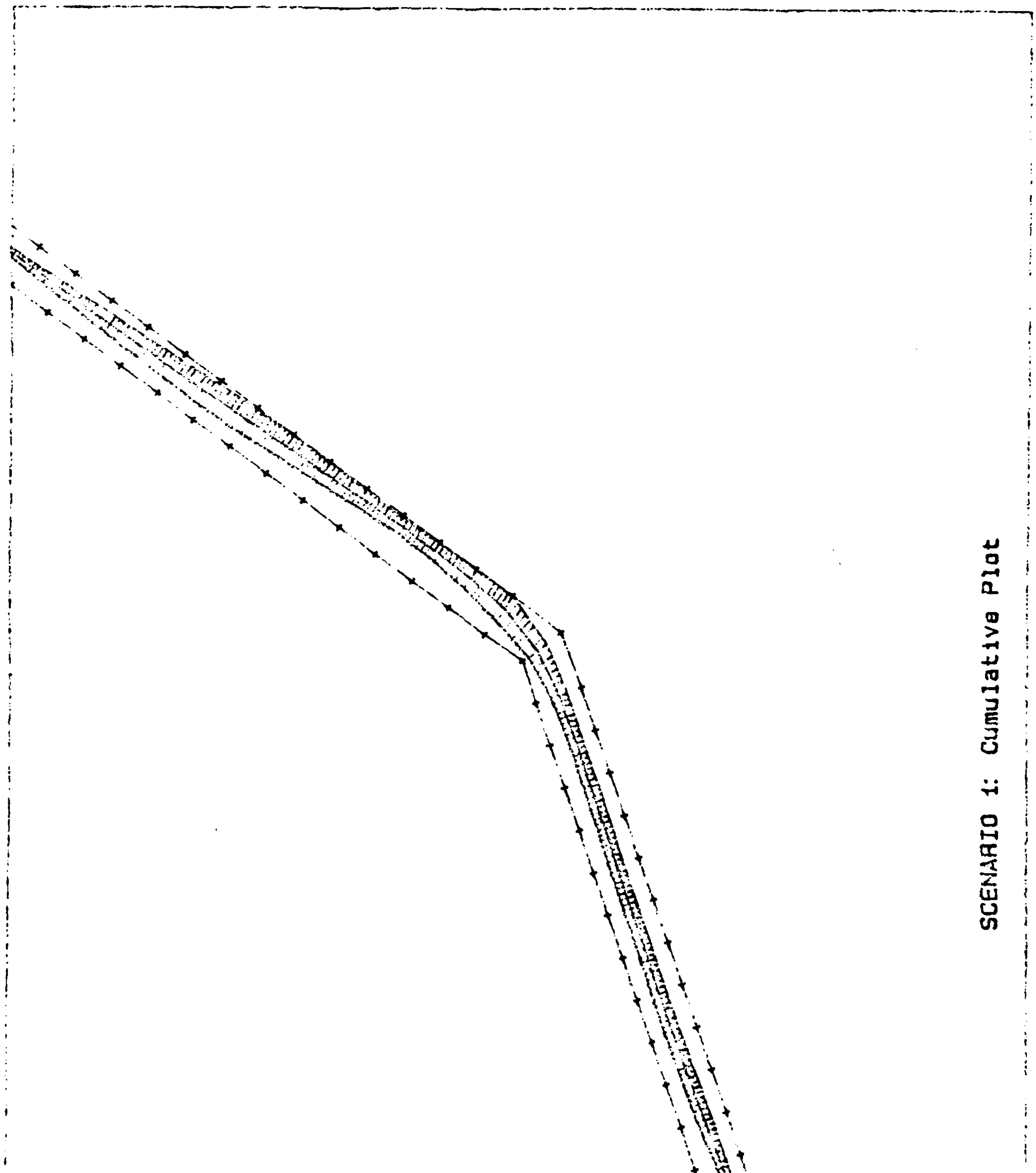
For those scenarios with fixed aids, aids are shown on the plots as circles. For scenarios with floating aids, aids are shown at their displaced positions as asterisks. In both cases, the symbols have been applied by hand for illustrative purposes and may not be at their exact simulator positions.

TABLE D-1. EXPERIMENTAL SCENARIOS

Scenario	Accuracy Classification	Current Direction	Current Speed	Aid Arrangement
Objective: Familiarization				
0	assigned position	341°T	decreasing	3-aid turn, gated aids, land, objects
Objective: Inclusion of Baseline Conditions (Fixed Aids/Decreasing Current)				
1	assigned position	341°T	decreasing	3-aid turn, gated aids
2	assigned position	341°T	decreasing	1-aid turn, staggered aids
Objective: Evaluation of Accuracy Classification (Distance)				
3	A (72 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
4	B (120 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
5	C (180 feet)	341°T	0.90 knots	3-buoy turn, gated buoys
Objective: Evaluation of Channel/Current Orientation (Direction)				
6	B (120 feet)	161°T	0.90 knots	3-buoy turn, gated buoys
7	B (120 feet)	306°T	0.90 knots	3-buoy turn, gated buoys
8	B (120 feet)	126°T	0.90 knots	3-buoy turn, gated buoys
Objective: Evaluation of Aid Arrangements for Environment				
9	B (120 feet)	341°T	0.90 knots	1-buoy turn, staggered buoys

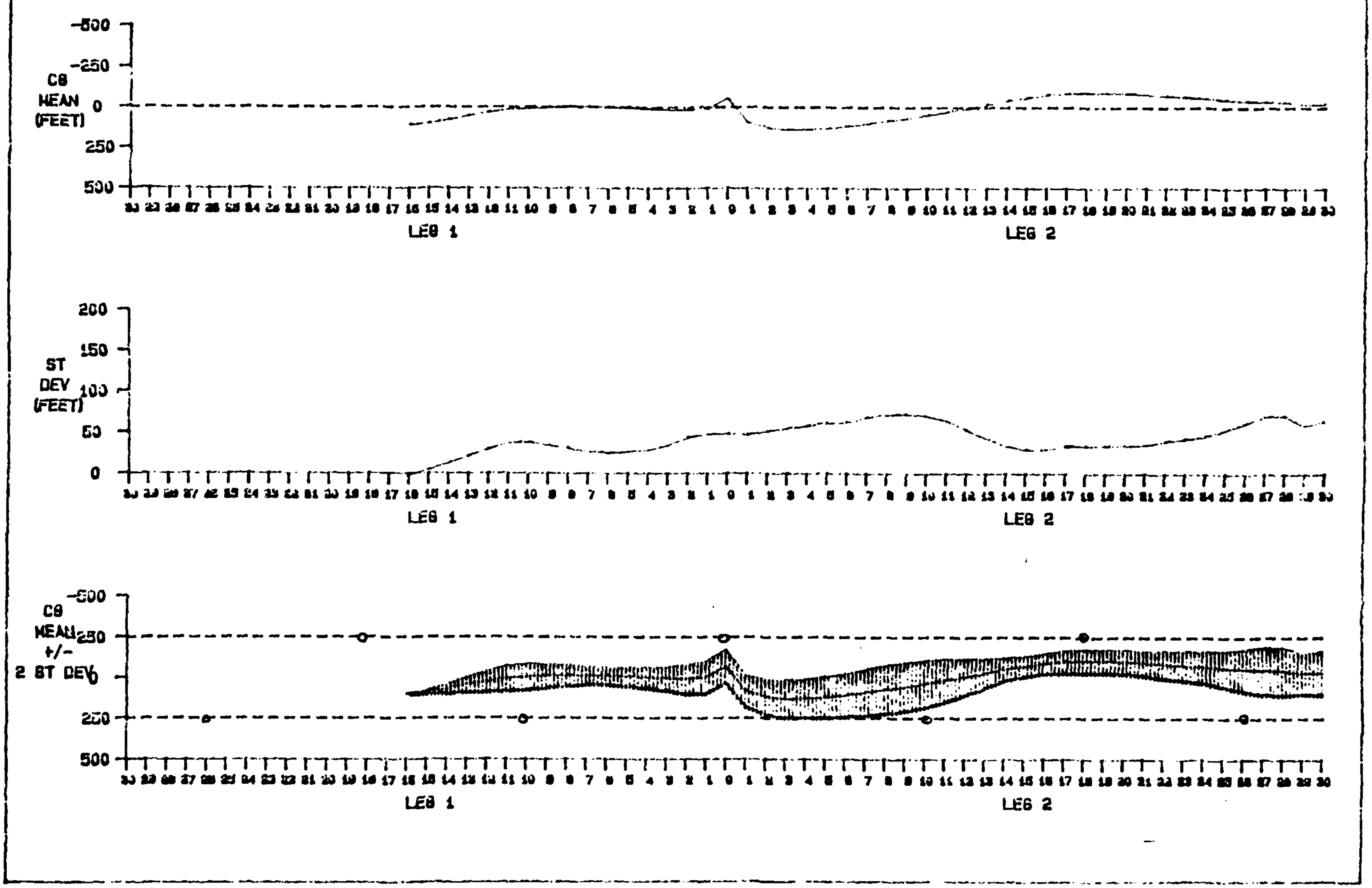
Scenario 1: Gated buoys at AP, Decreasing Current

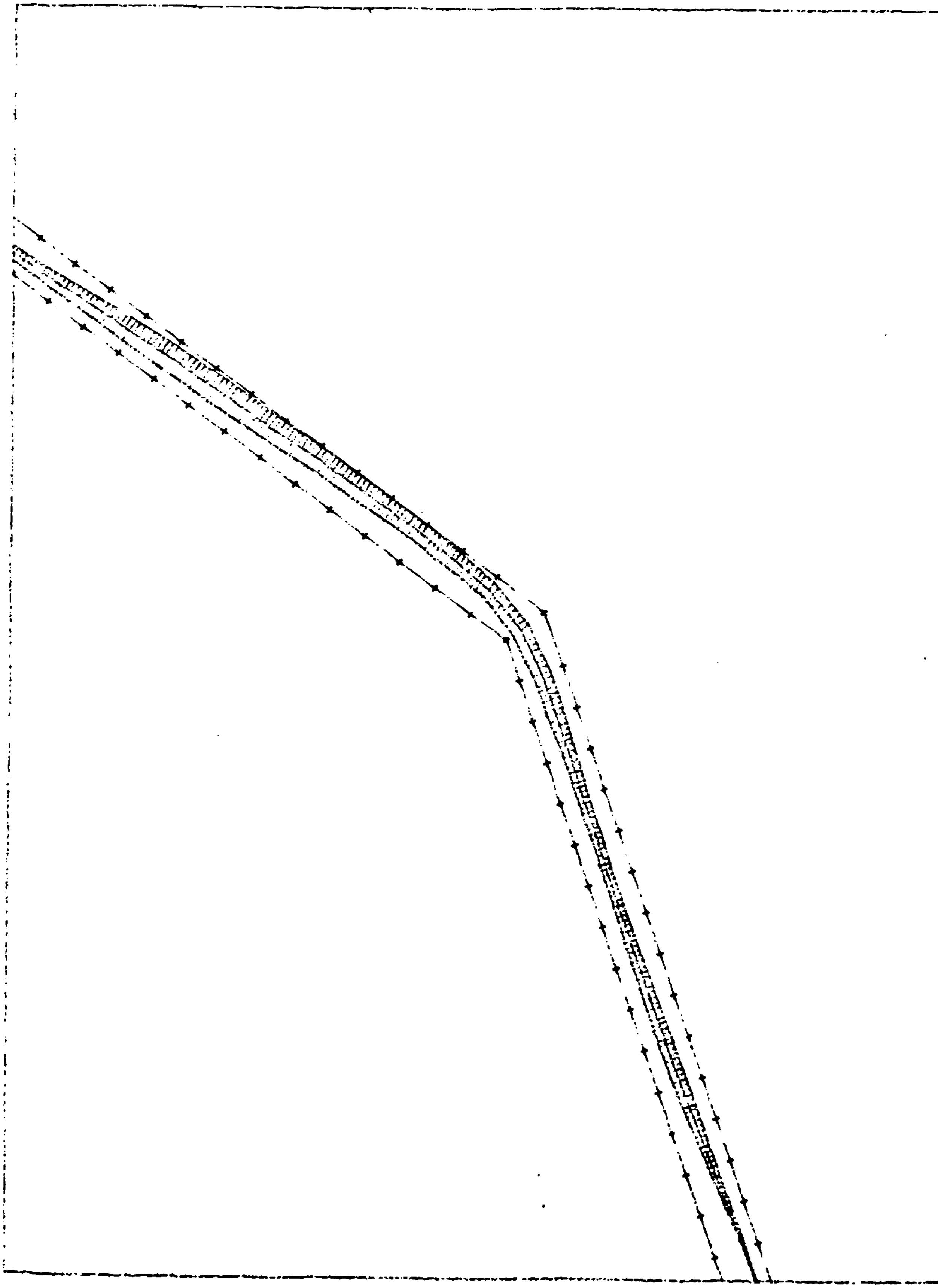




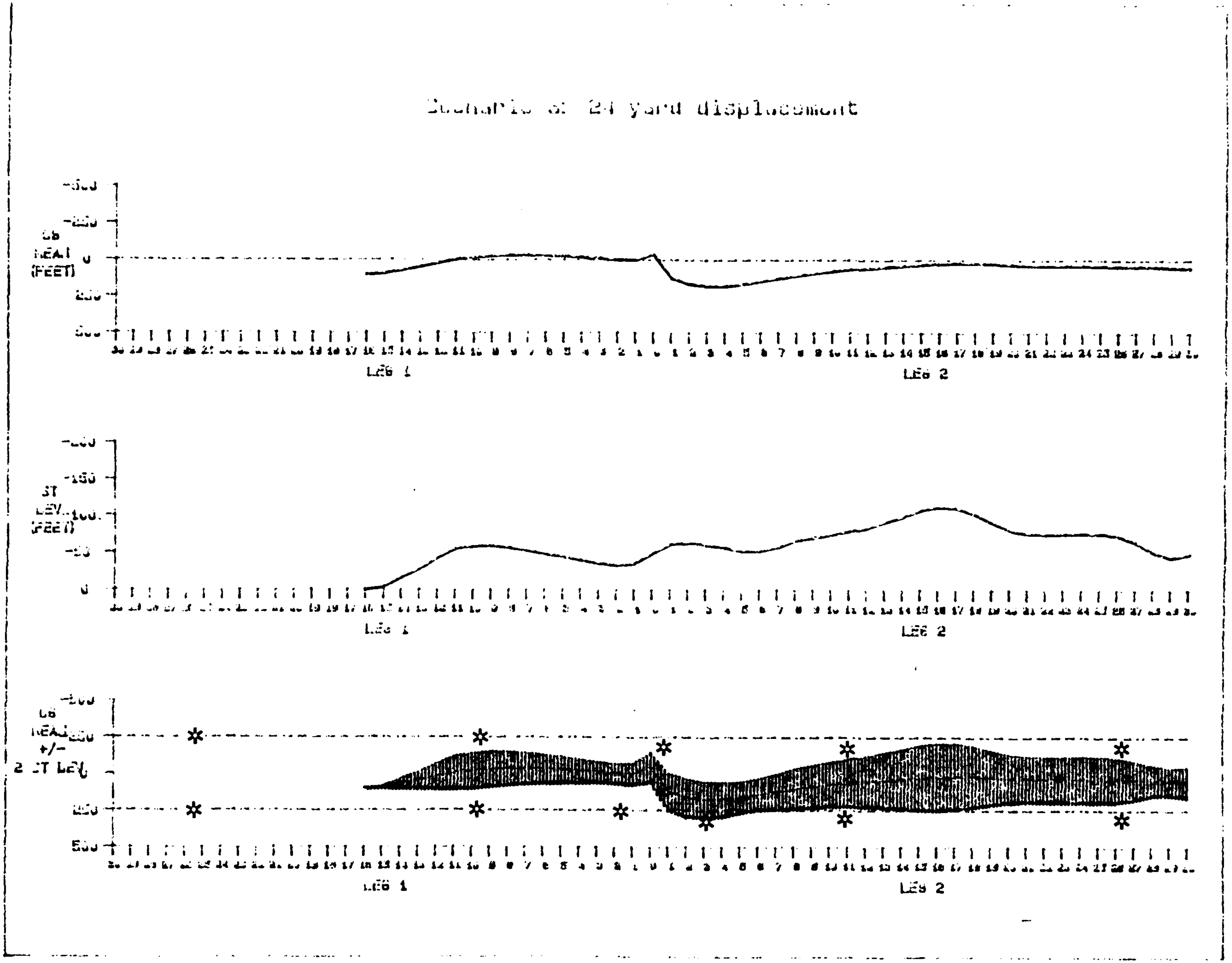
SCENARIO 1: Cumulative Plot

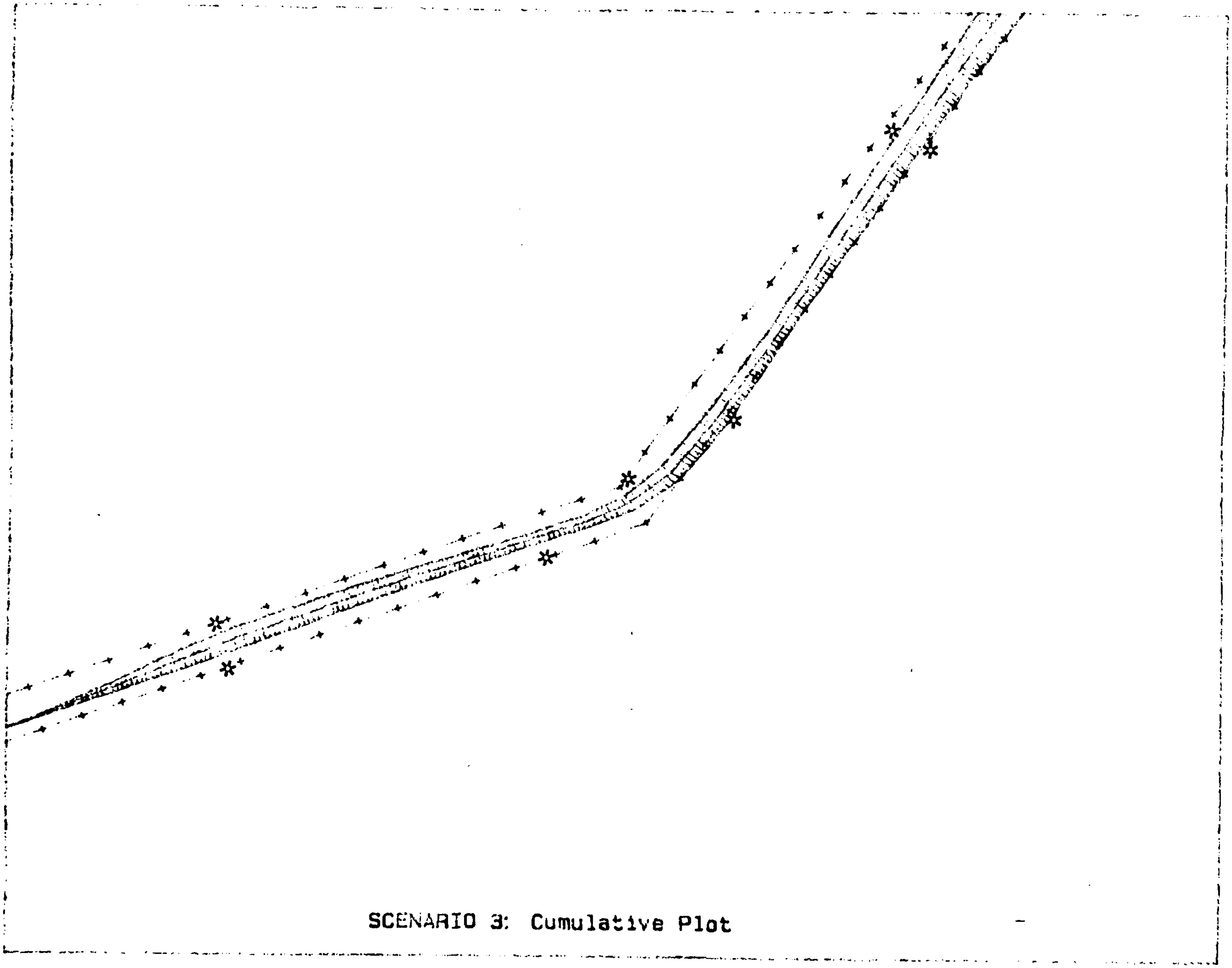
Scenario 2: Staggered buoys at AP, Decreasing Current



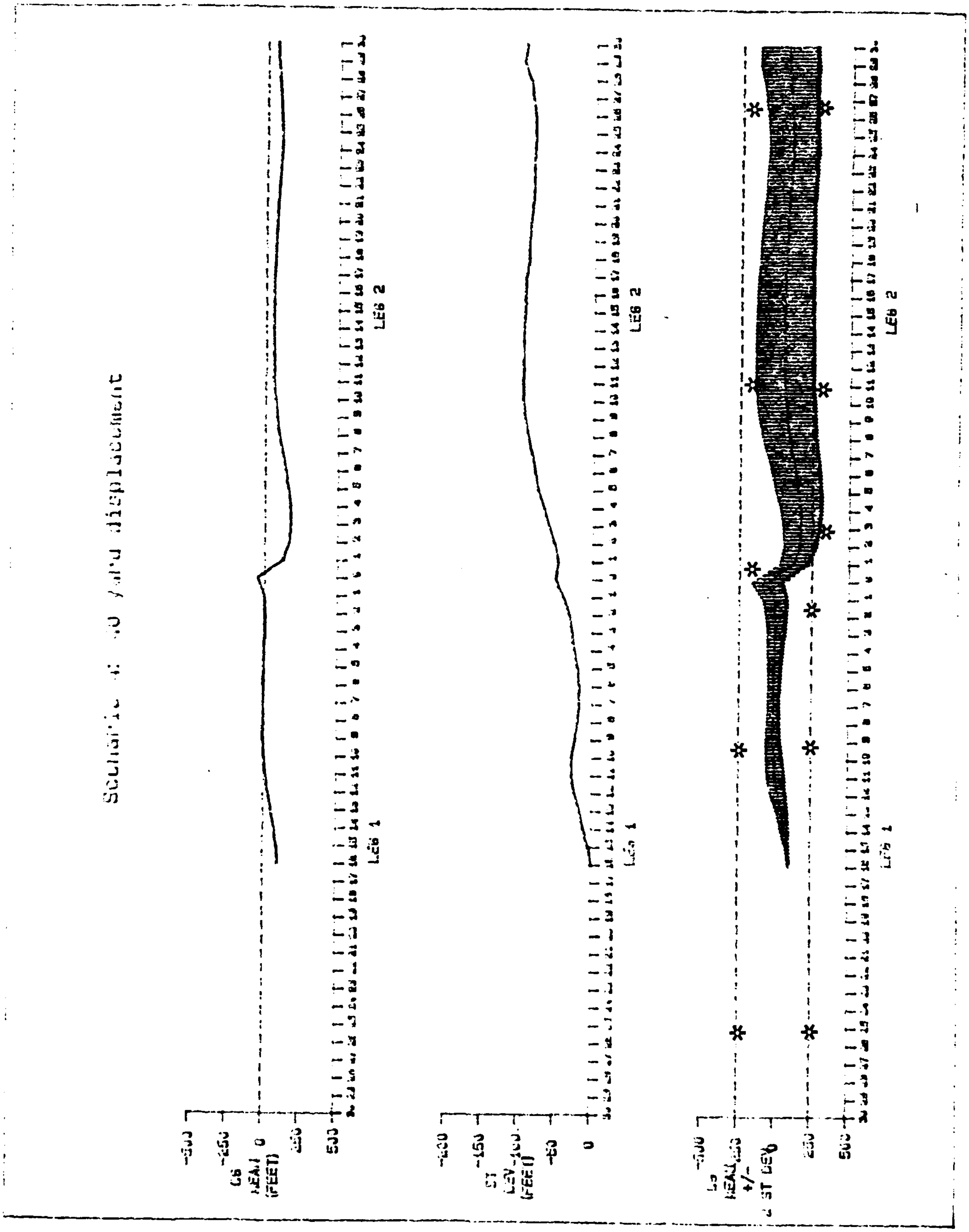


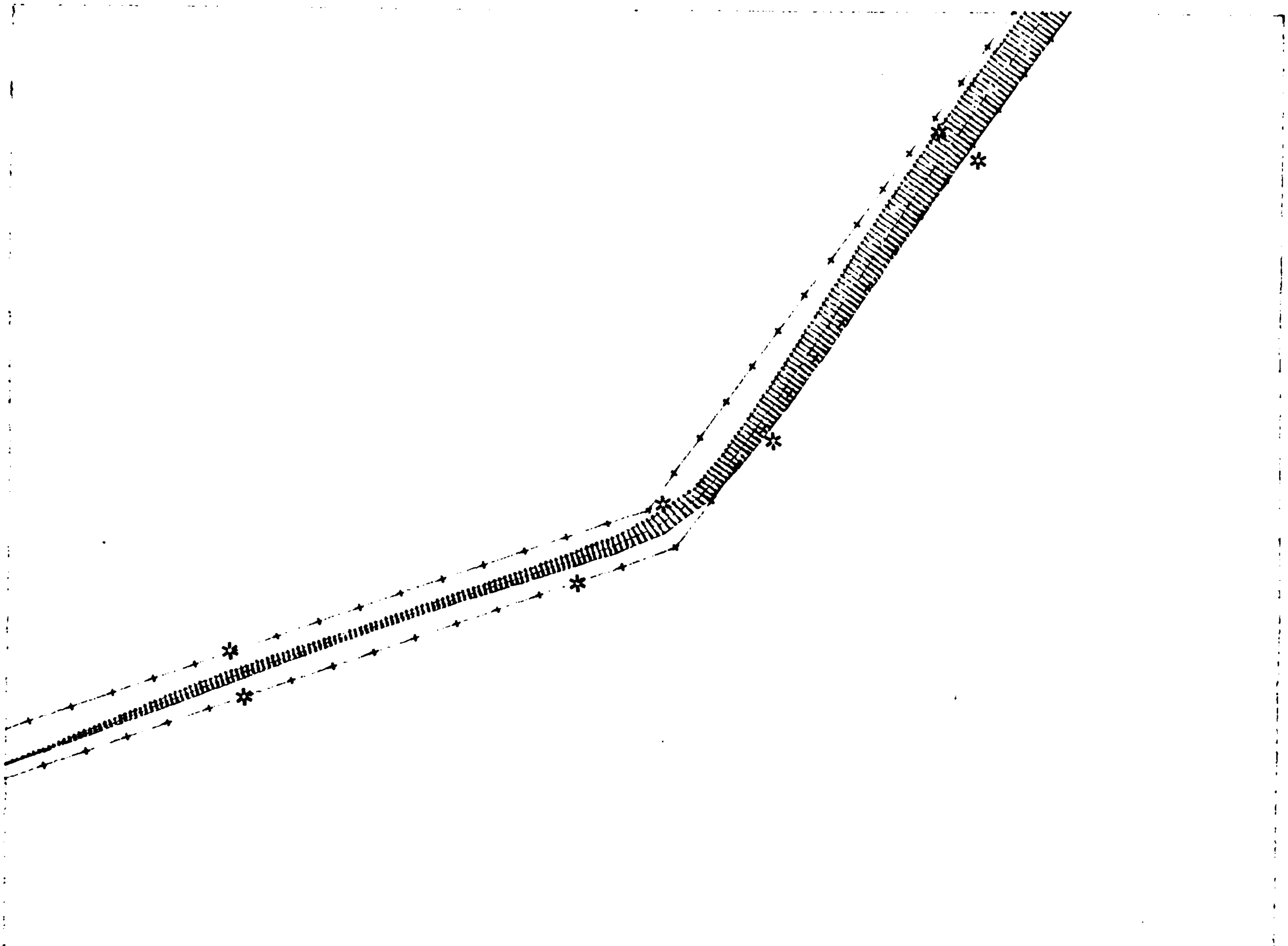
SCENARIO 2: Cumulative Plot


(FEET)
LEG 1
LEG 2
+/-



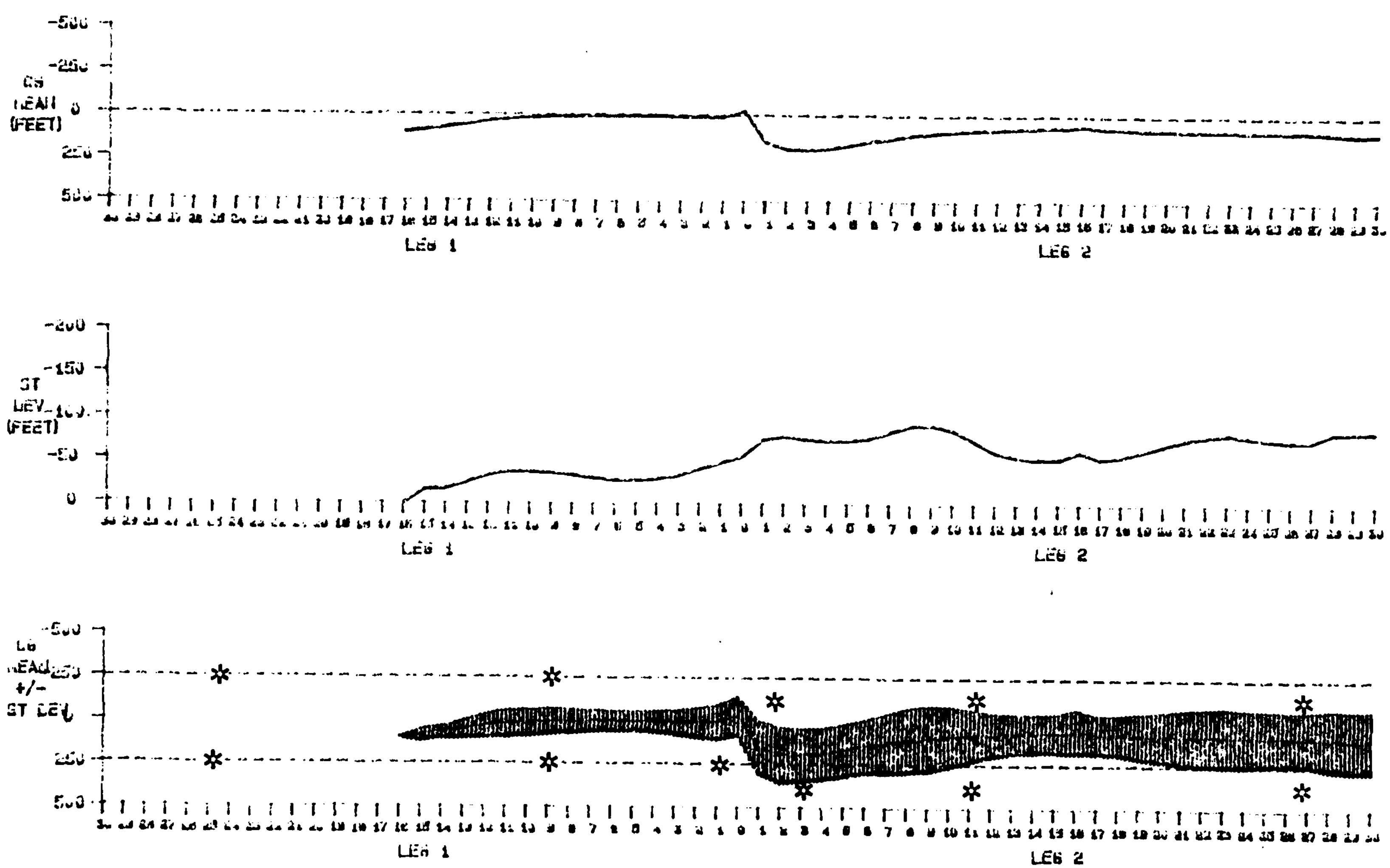
SCENARIO 3: Cumulative Plot

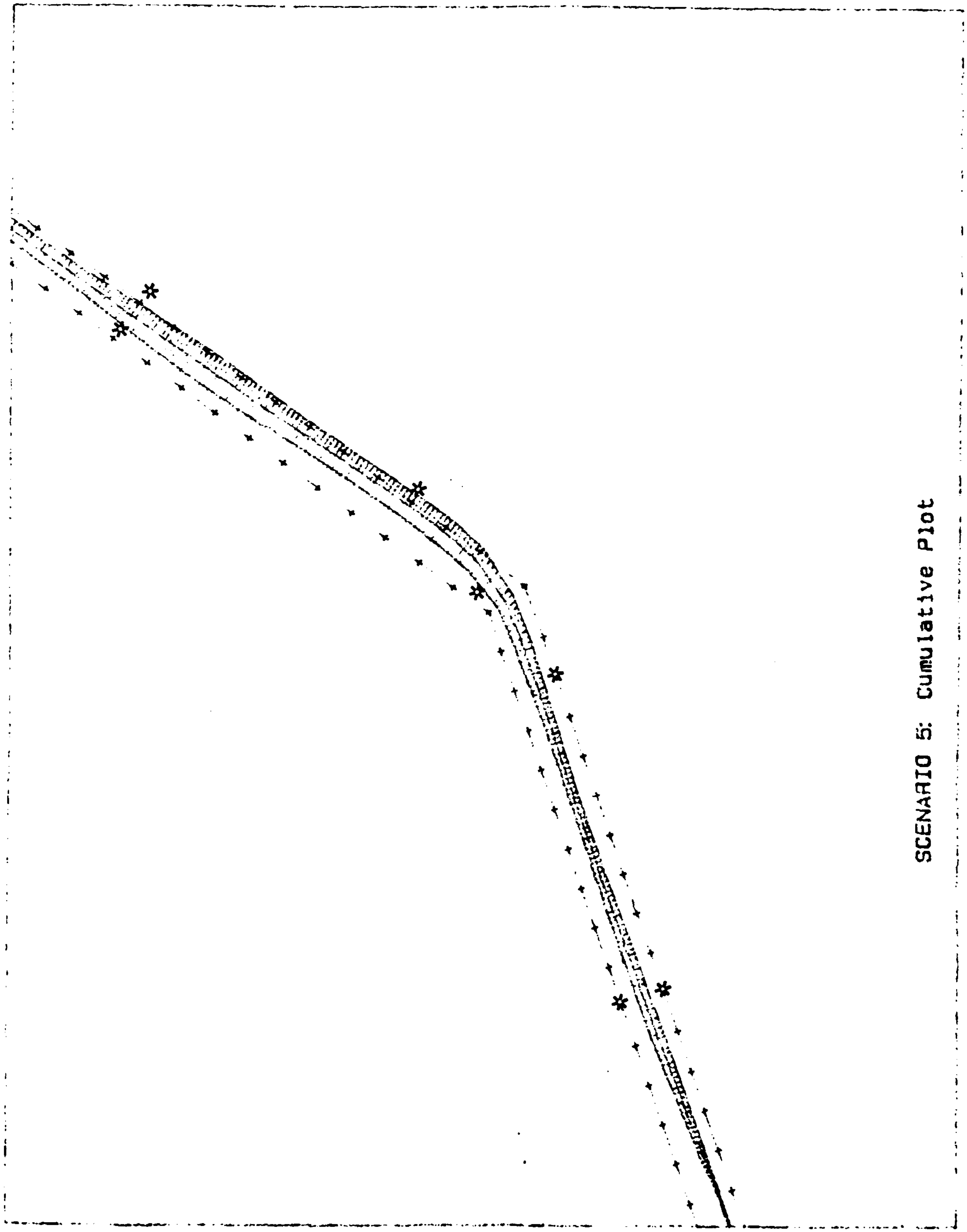

LEG 1
LEG 2
MEAN (FEET)
ST DEV (FEET)
+/-
ST DEV



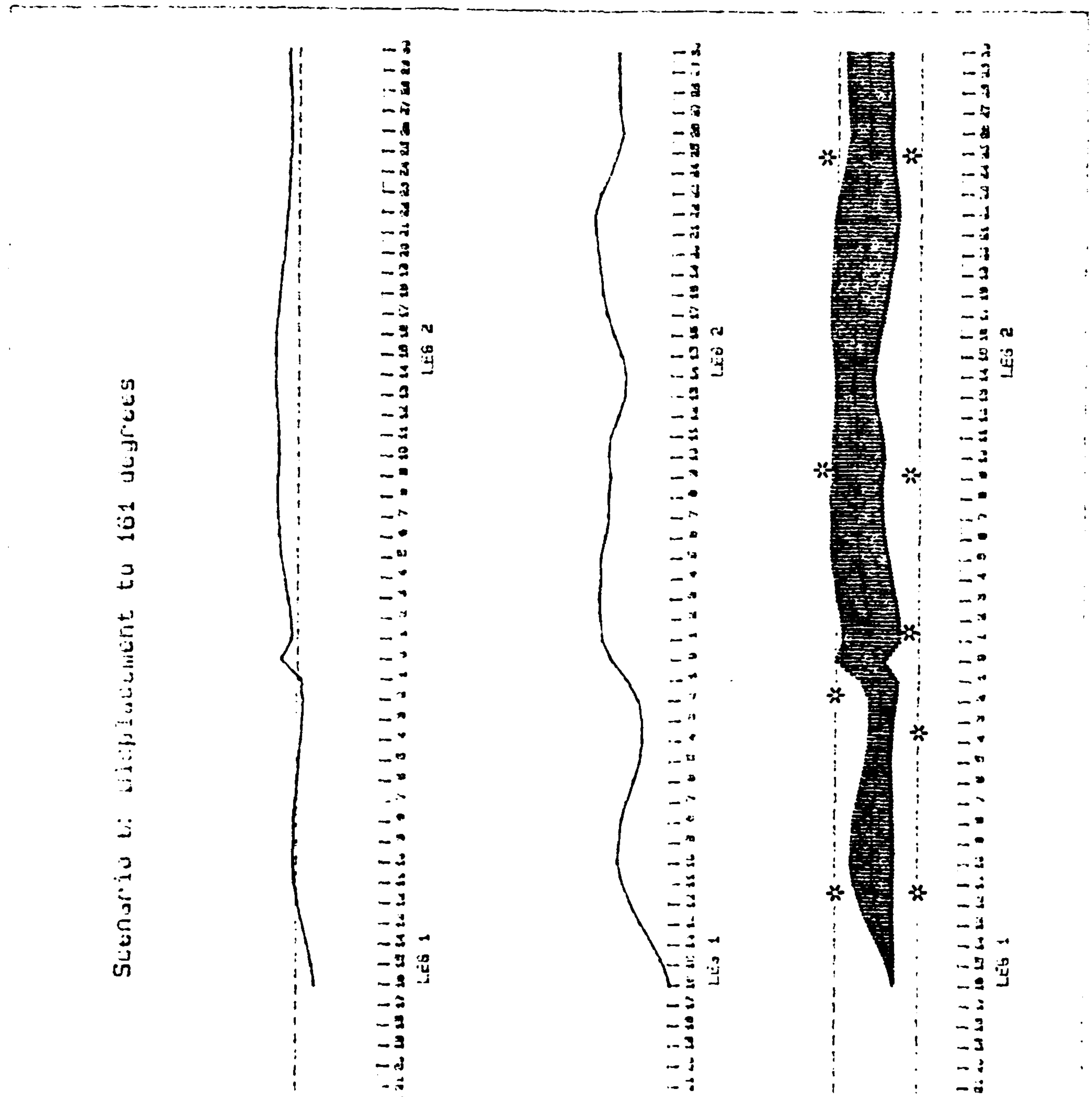
SCENARIO 4: Cumulative Plot

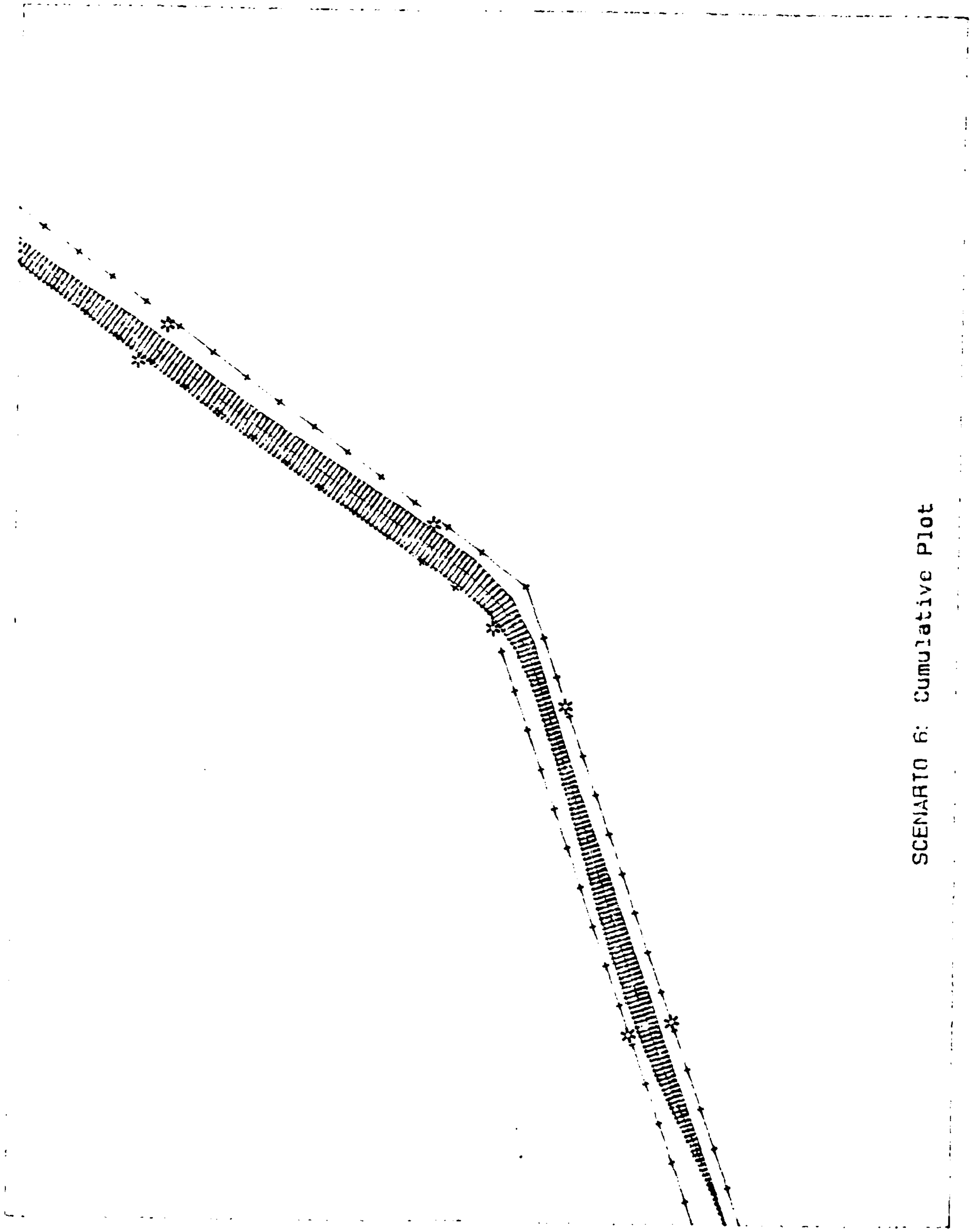
Scenario [illegible]: 60 yard displacement





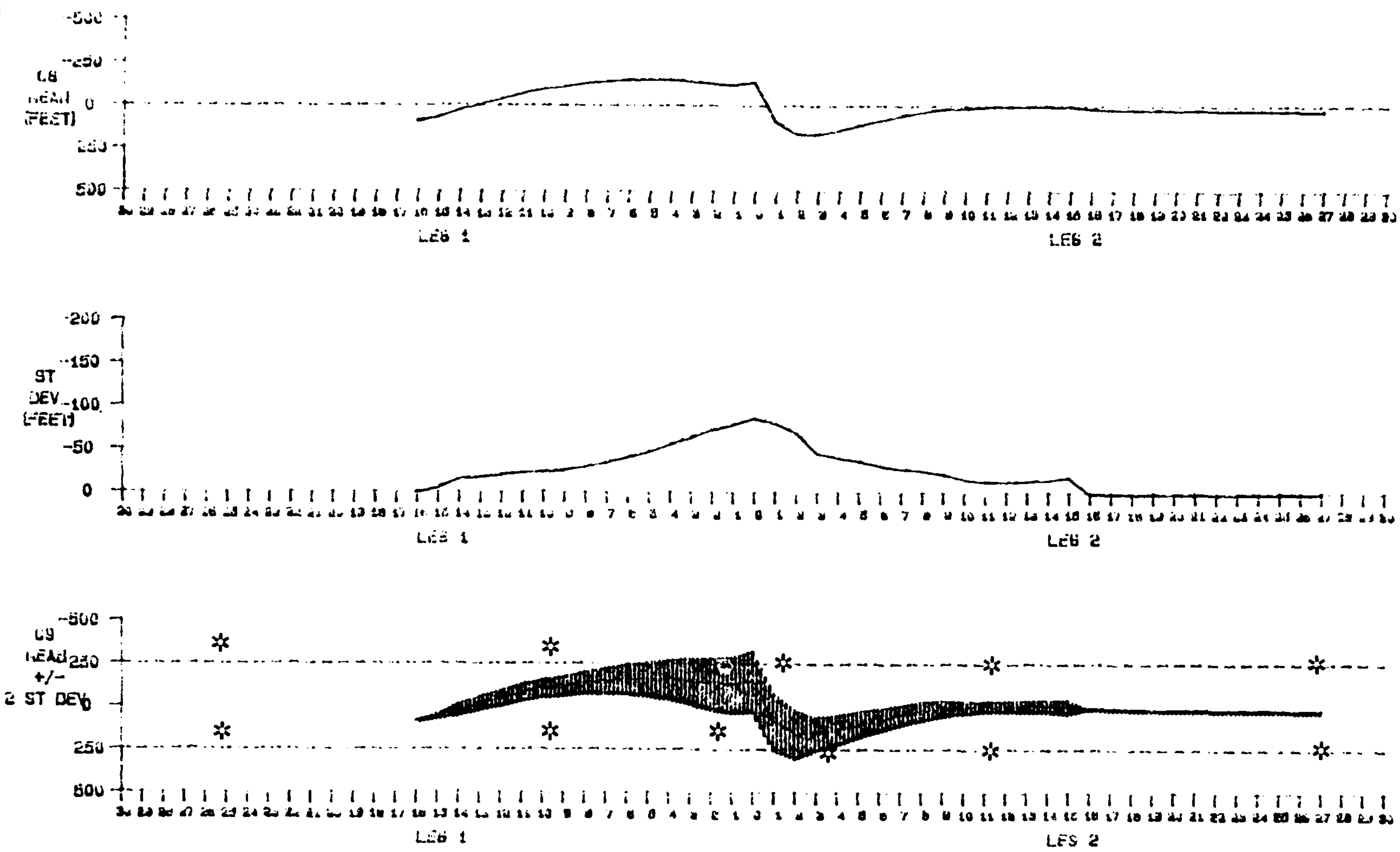
SCENARIO 5: Cumulative Plot

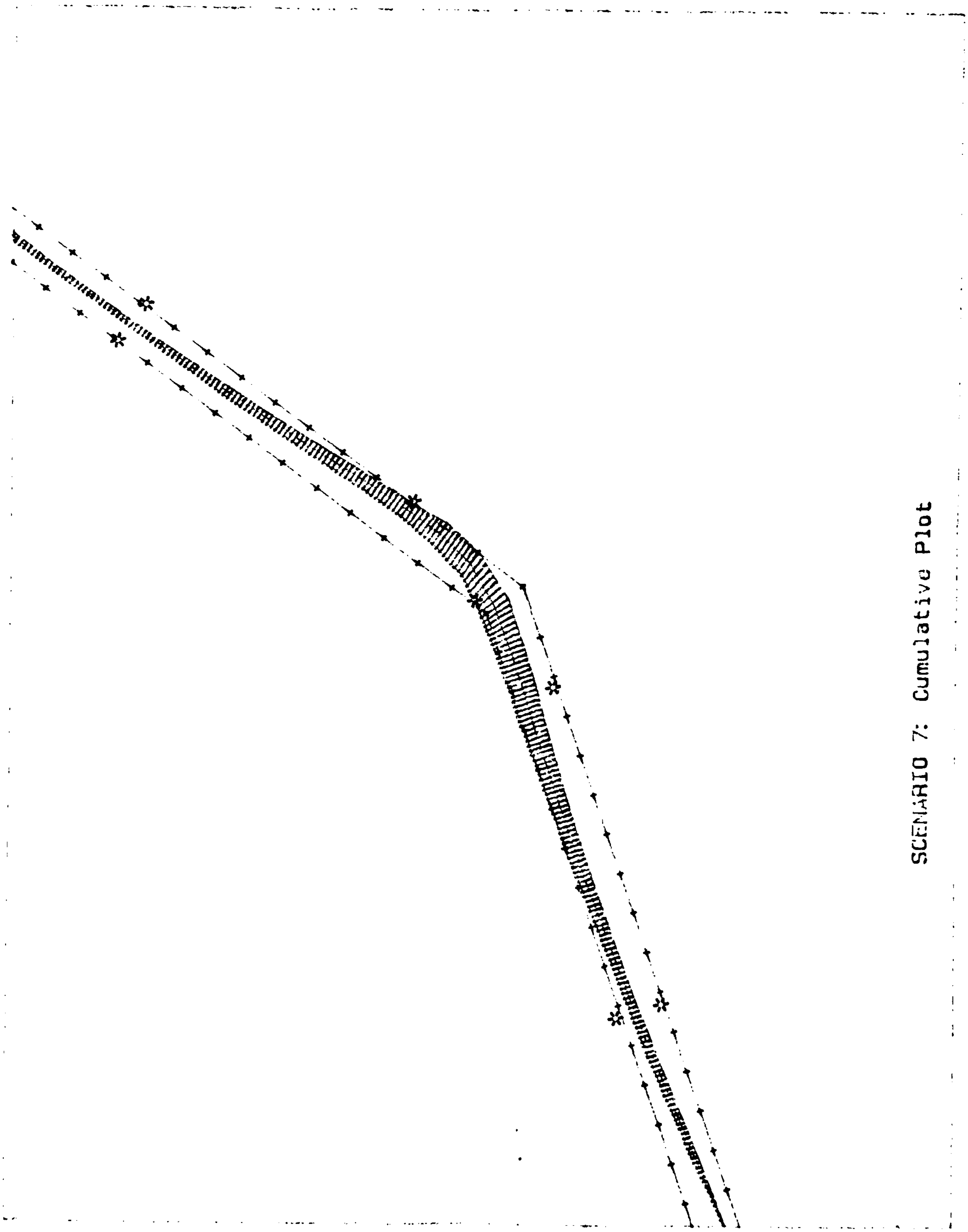

displacement to 161 degrees
LEG 1
LEG 2
MEAN (FEET)
ST DEV (FEET)
+/-
2 ST DEV
-500
-250
0
250
500
-200
-150
-100
-50



SCENARIO 6: Cumulative Plot

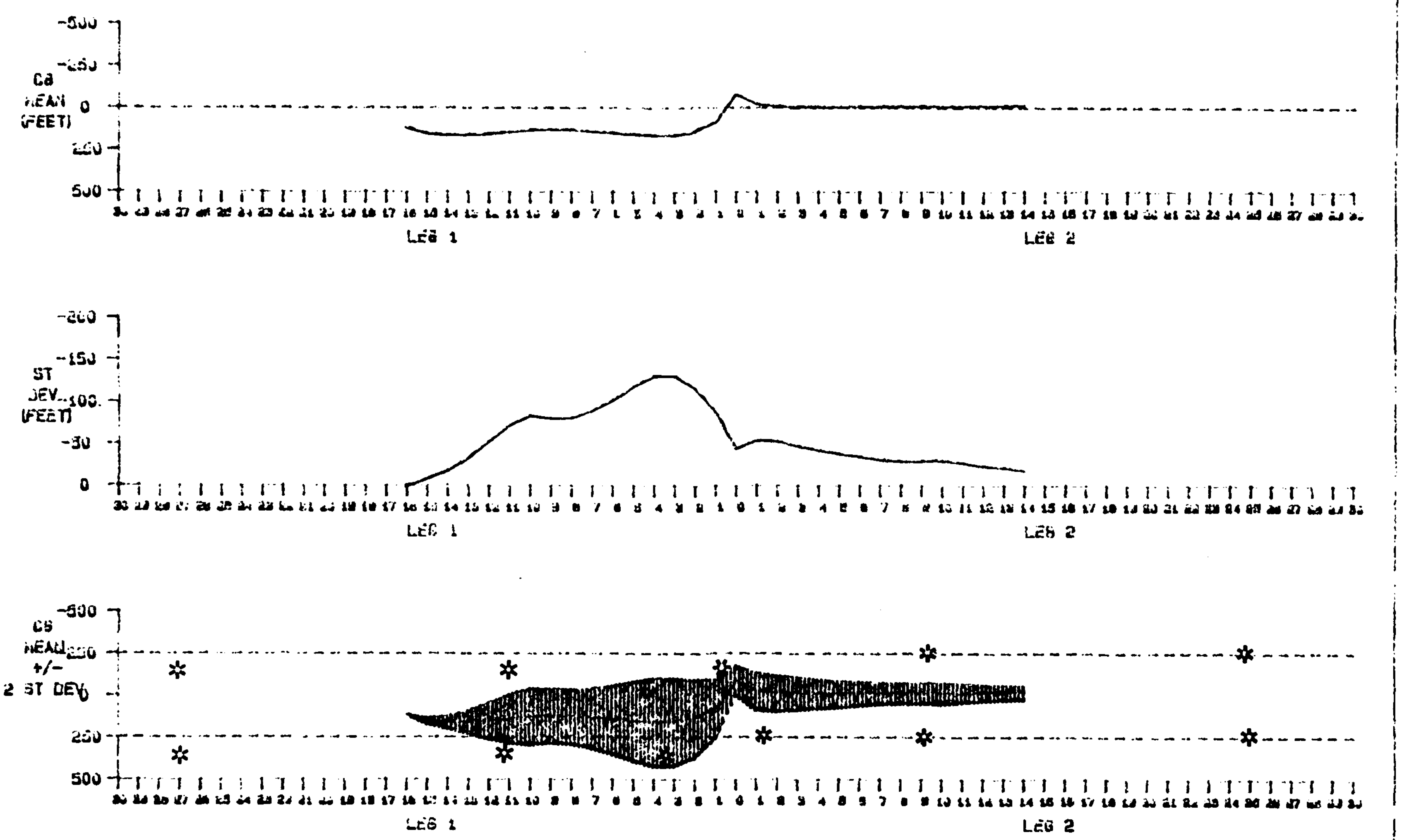
Scenario 7: Displacement to 306 degrees

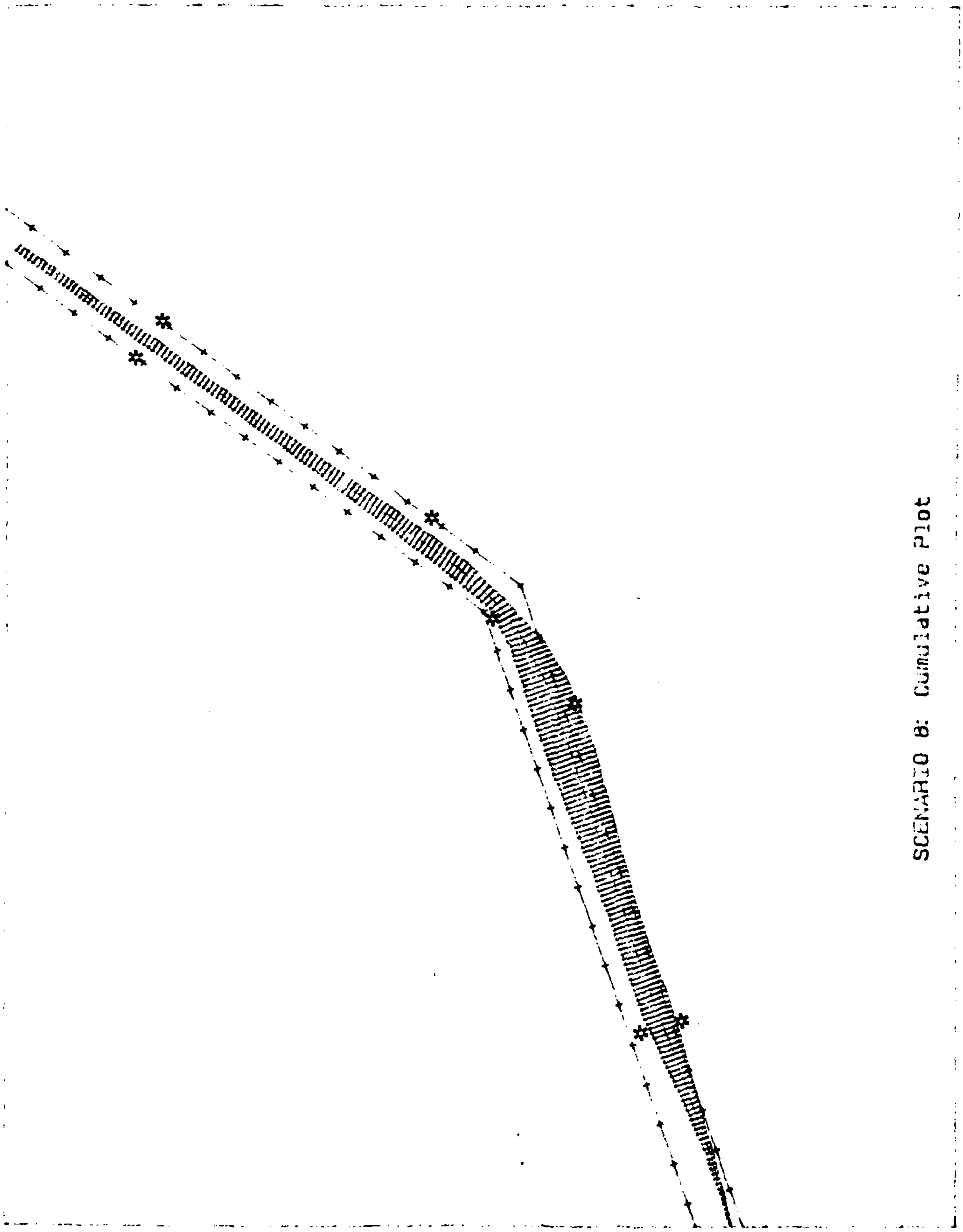




SCENARIO 7: Cumulative Plot

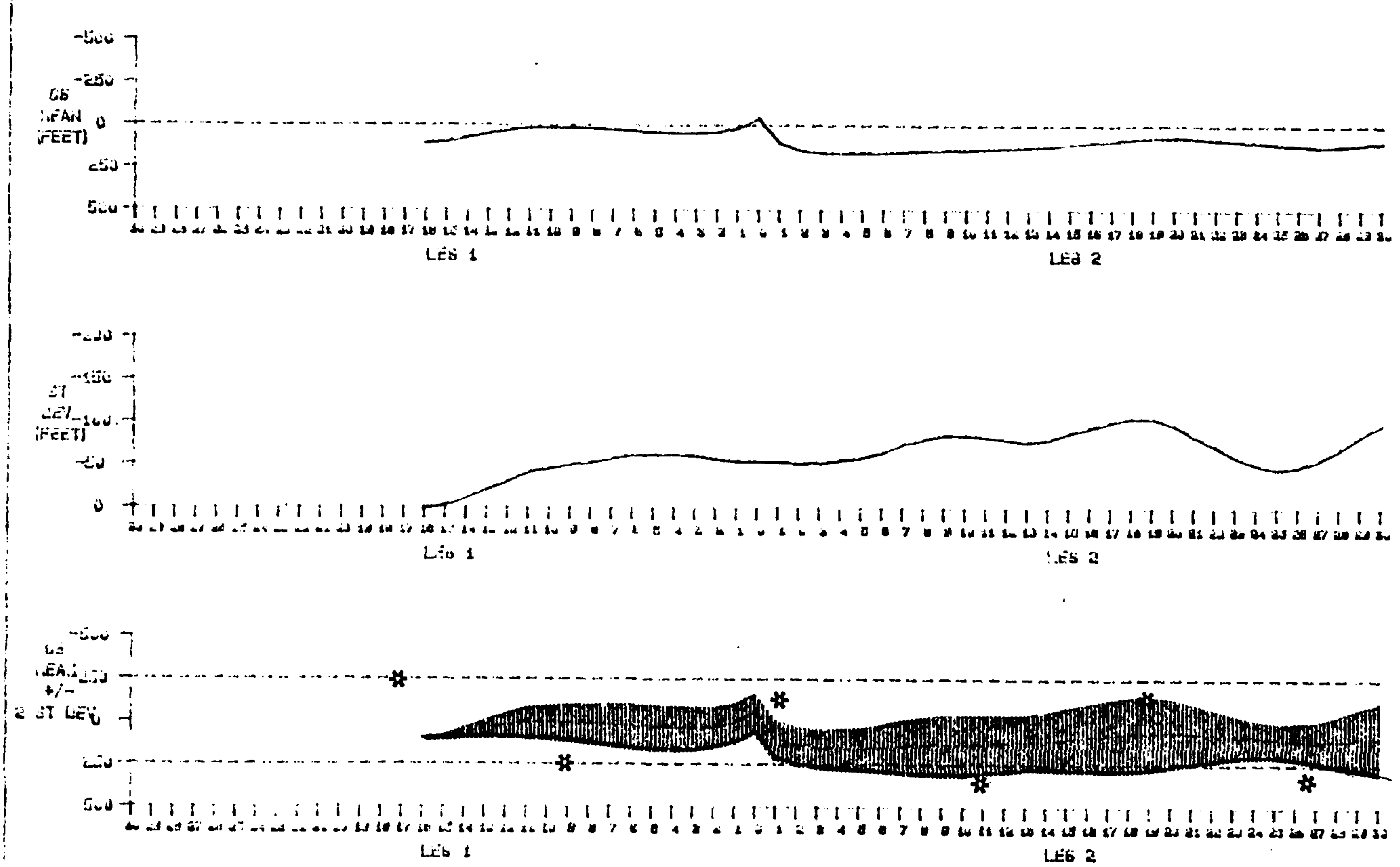
Scenario 6: Displacement to 120 degrees

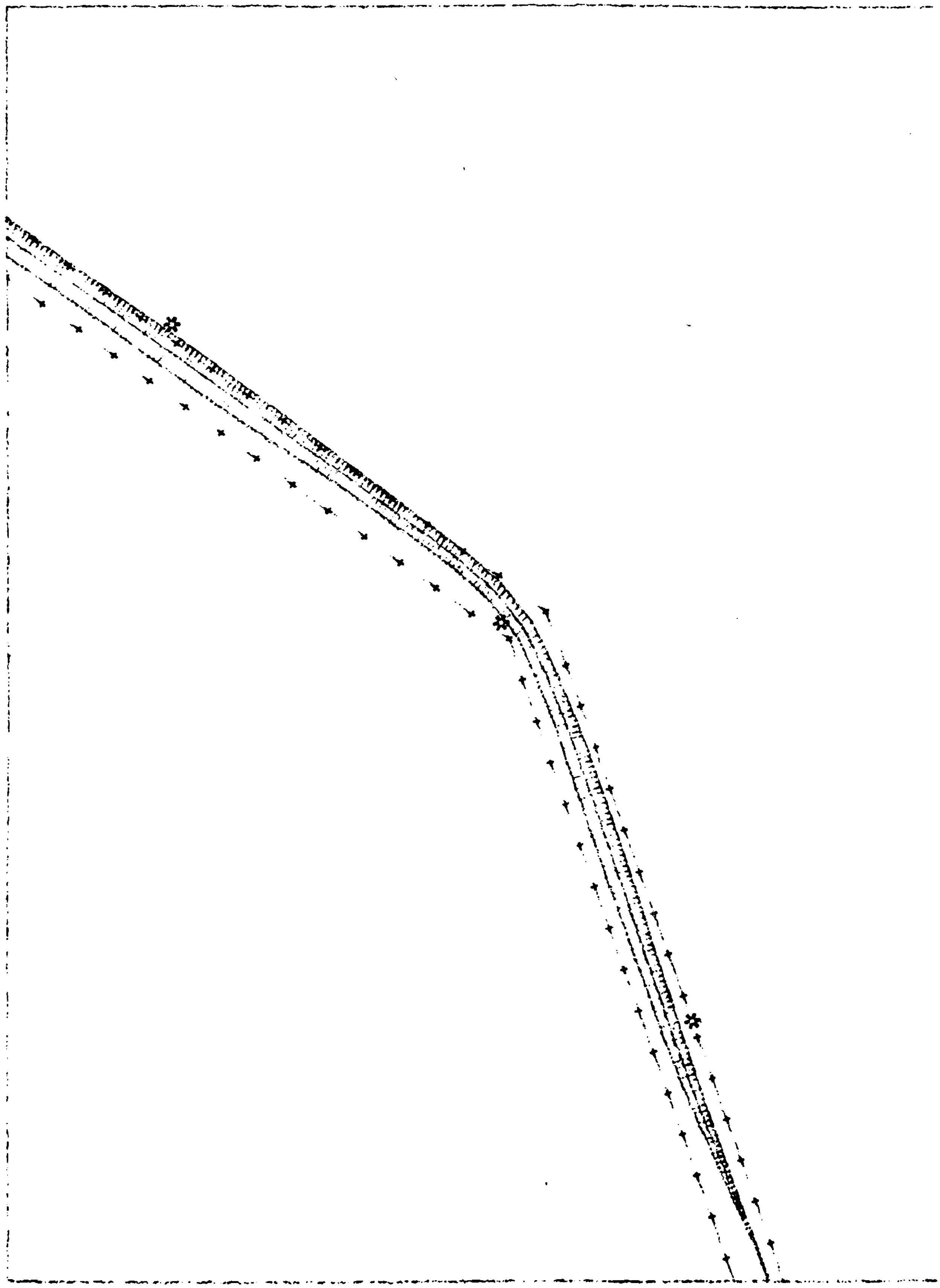




SCENARIO 8: Cumulative Plot

Scenario 9: Staggered buoys, 40 yard displacement





SCENARIO 9: Cumulative Plot

Appendix E

COMPARISON PLOTS FOR EXPERIMENTAL RESULTS

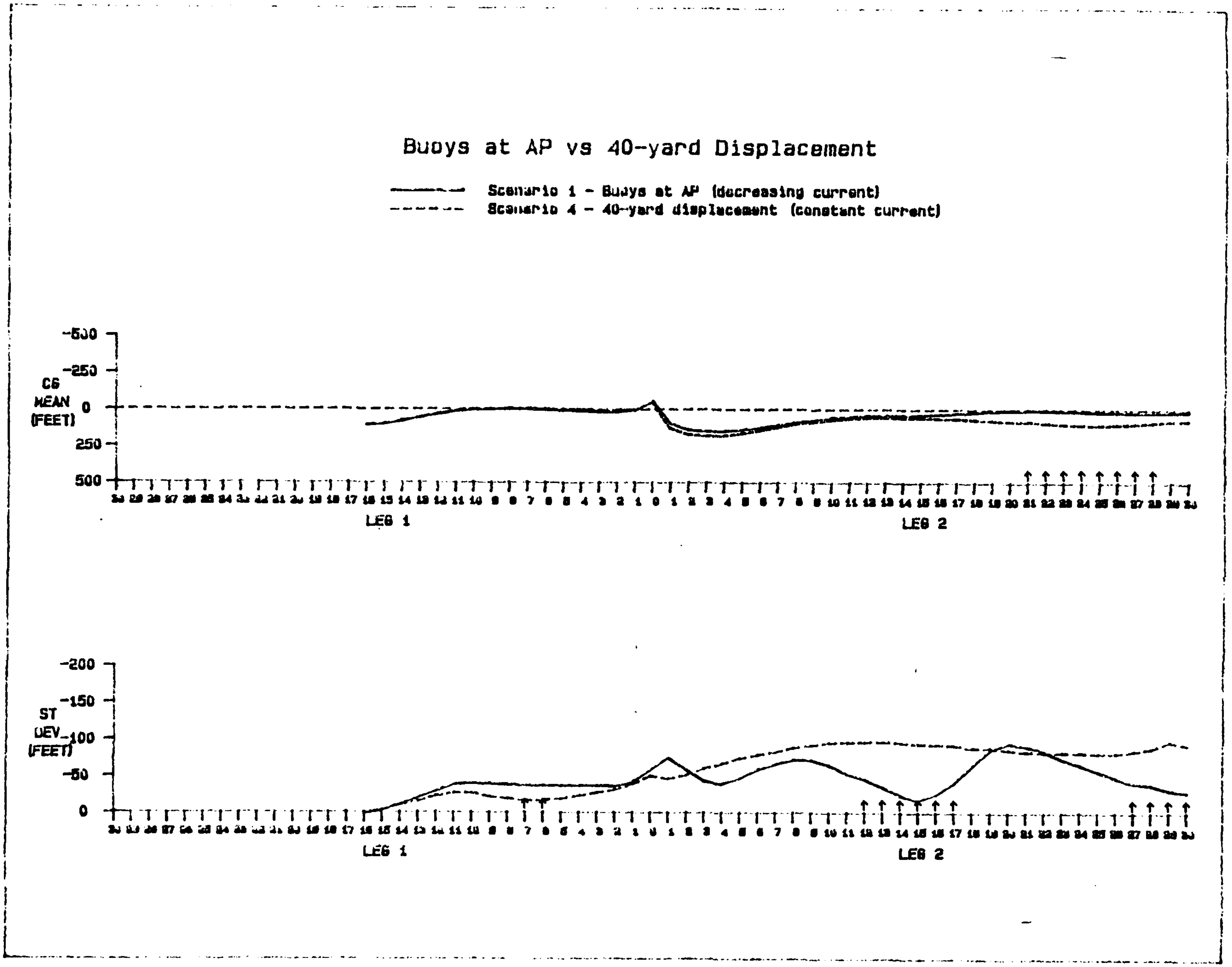
The plots which follow are a graphic representation of the comparisons on which the discussions in Section 5 were based. They are arranged according to the outlines of the section. For each subsection there is a "comparison" plot comparing statistics from the two scenarios. This type of plot has been described in Section 4.3. These comparisons are summarized in Table E-1, which is repeated from the text as a convenience for the reader.

For each comparison there are two sets of axes, one showing the mean and one showing the crosstrack standard deviation as the performance measures. Data is plotted as a continuous unbroken line and a dotted line to distinguish the experimental conditions from each other.

Statistical tests were used to test differences in performance at each data line, to determine if any differences between the conditions were statistically significant. The means were compared using a t-test. The arrows along the axis of the mean plot indicate a difference at the 0.10 level of significance. The standard deviations were compared as variances using an F test. The arrows along the axis of the standard deviation plot also indicate a difference at the 0.10 level of significance.

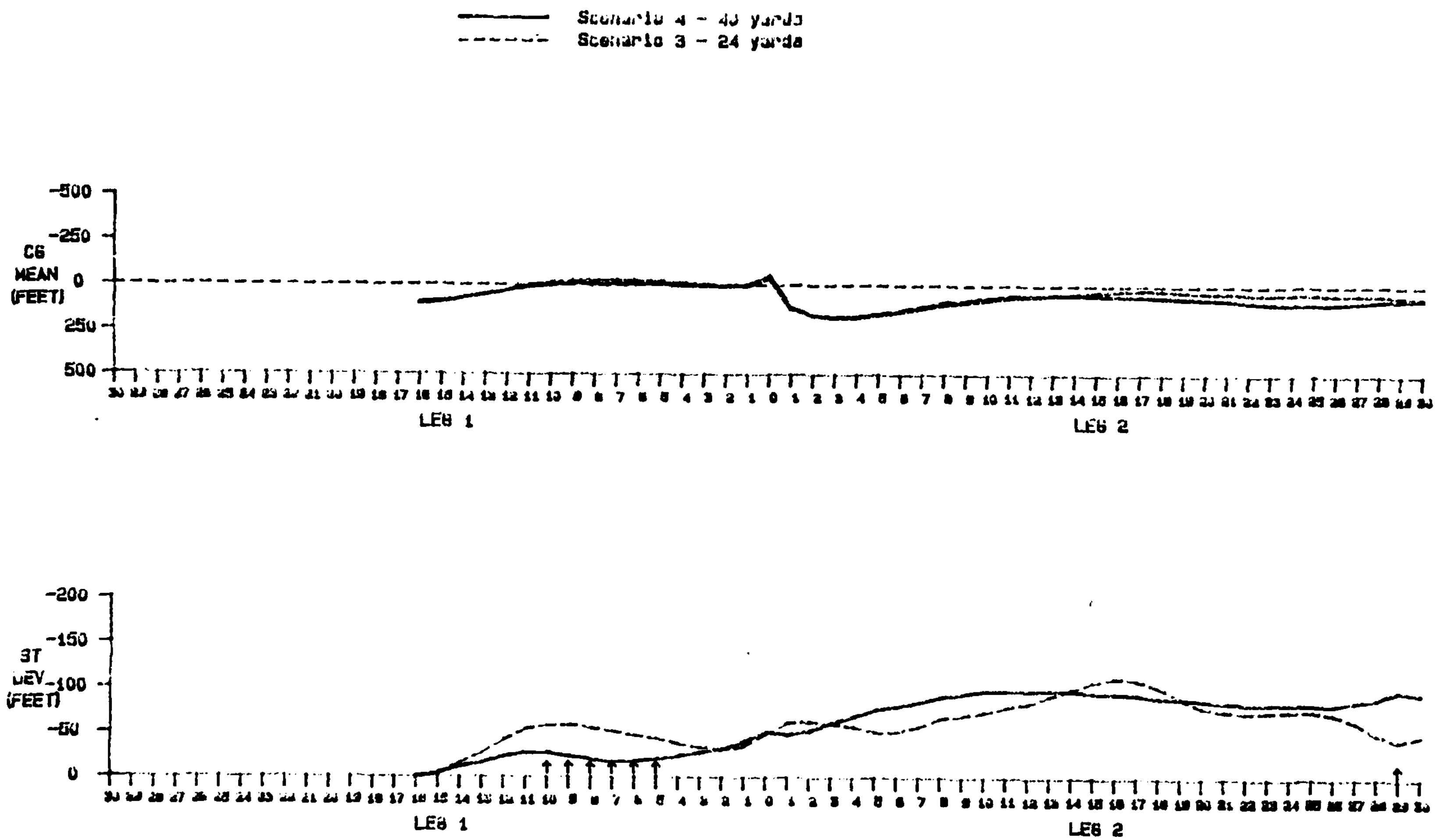
TABLE E-1. COMPARISONS BETWEEN EXPERIMENT SCENARIOS

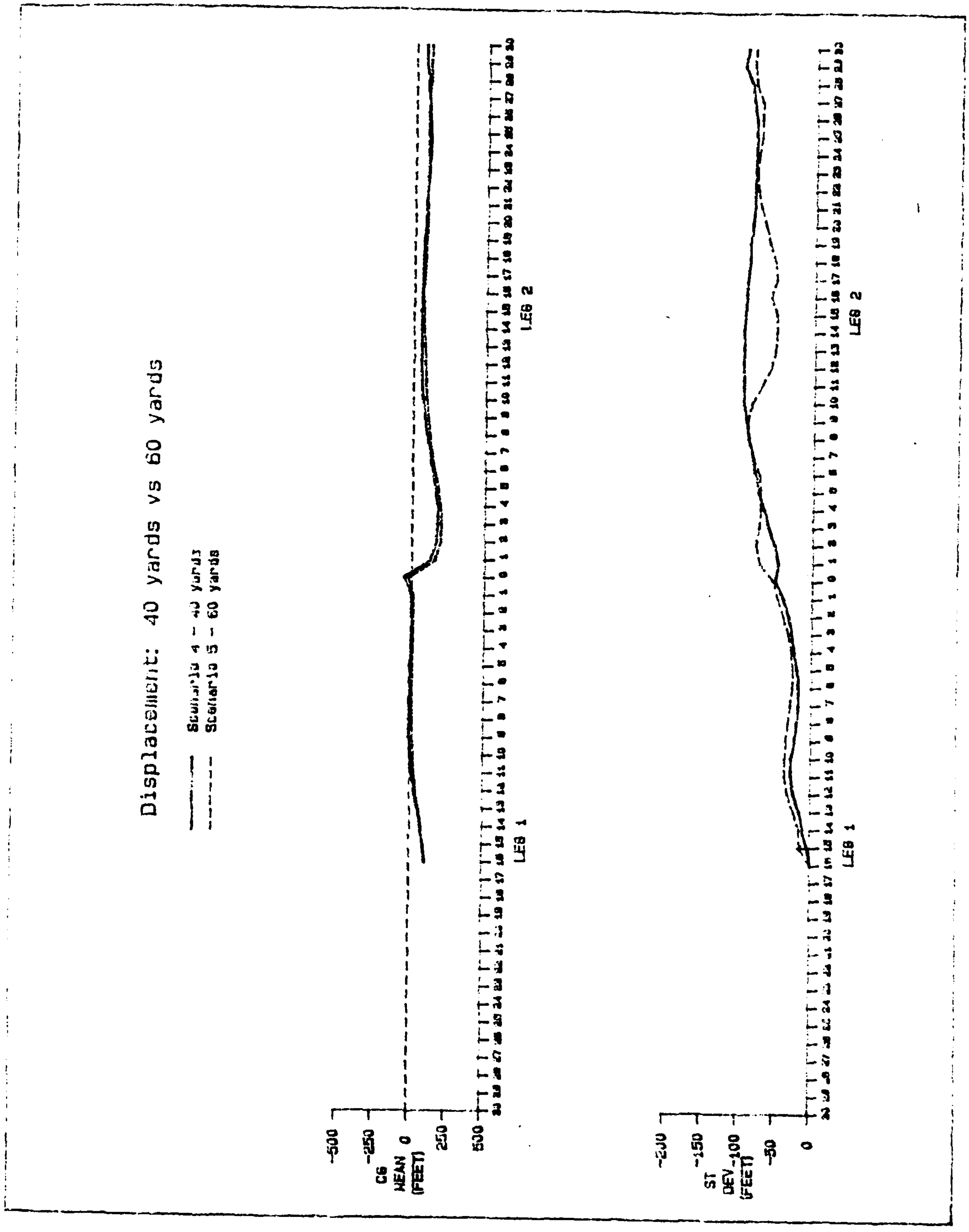
EFFECT	SCENARIOS
Fixed Aids Versus Floating Aids	
With 3-Aid Turn/Gated Aids	1 vs 4
Accuracy Classification (Distance)	
A (72 feet) versus B (120 feet)	3 vs 4
B (120 feet) versus C (180 feet)	4 vs 5
A (72 feet) versus C (180 feet)	3 vs 5
Channel/Current Orientation (Direction)	
Crosscurrent in Turn Pullout Leg: (341°T versus 161°T)	4 vs 6
Parallel Current in Turn Pullout Leg: (306°T versus 126°T)	7 vs 8
Aid Arrangements	
Fixed Aids: 3-Aid Turn/Gated Aids versus 1-Aid Turn/Staggered Aids	1 vs 2
Floating Aids: 3-Aid Turn/Gated Aids versus 1-Aid Turn/Staggered Aids	4 vs 9



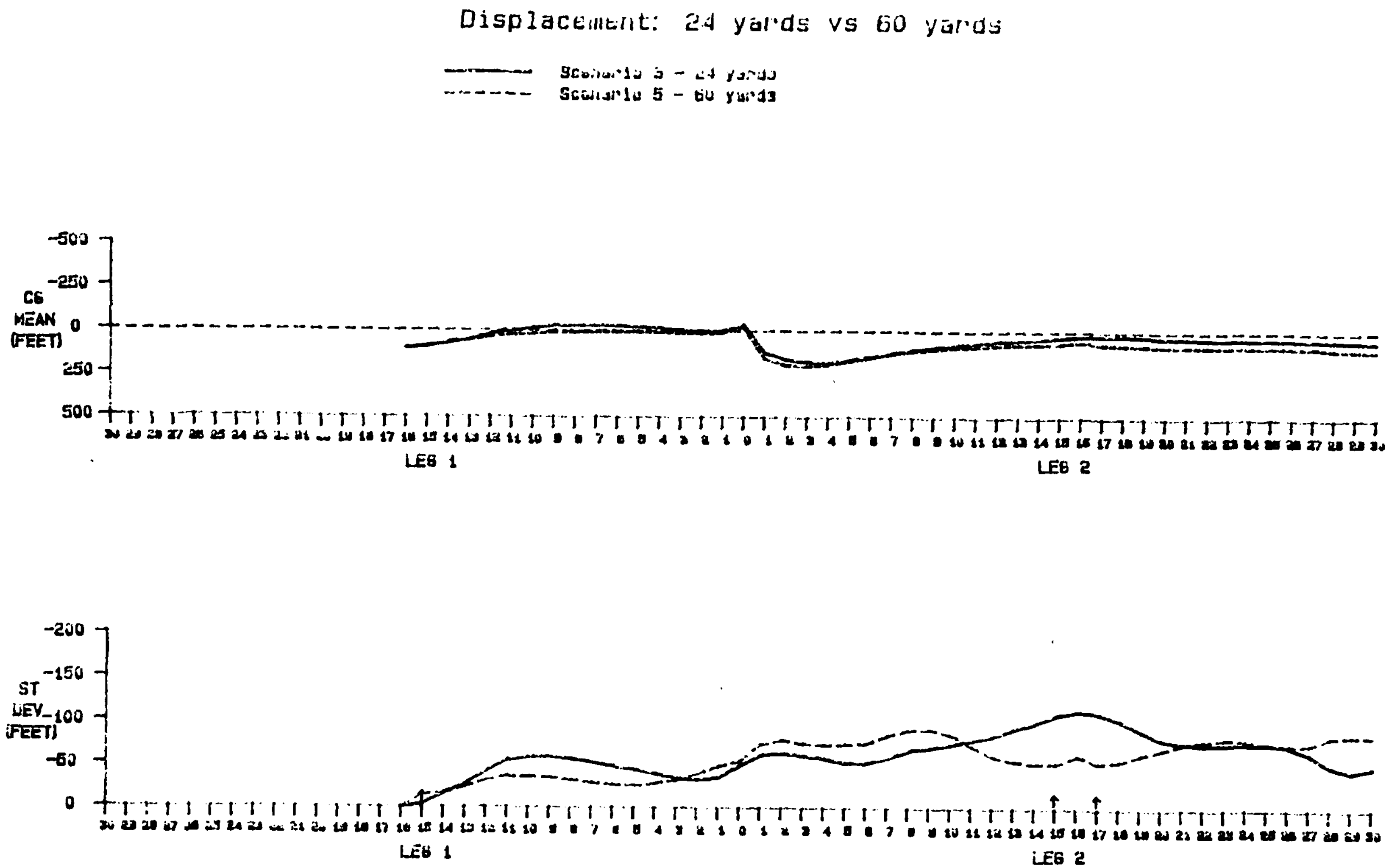
Buoys at AP vs 40-yard Displacement
Scenario 1 - Buoys at AP (decreasing current)
Scenario 4 - 40-yard displacement (constant current)
CG MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2

Displacement: 40 yards vs 24 yards



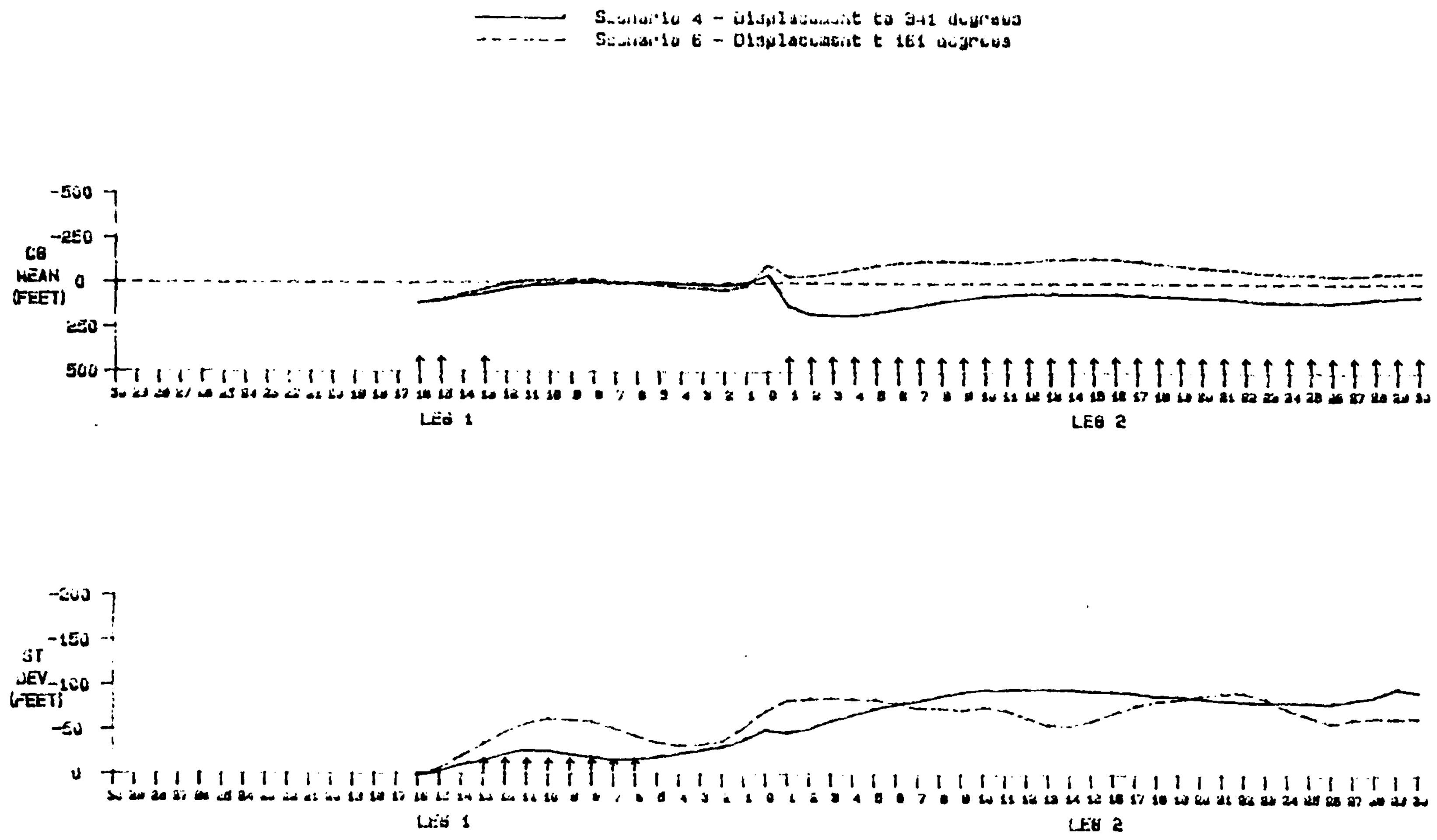


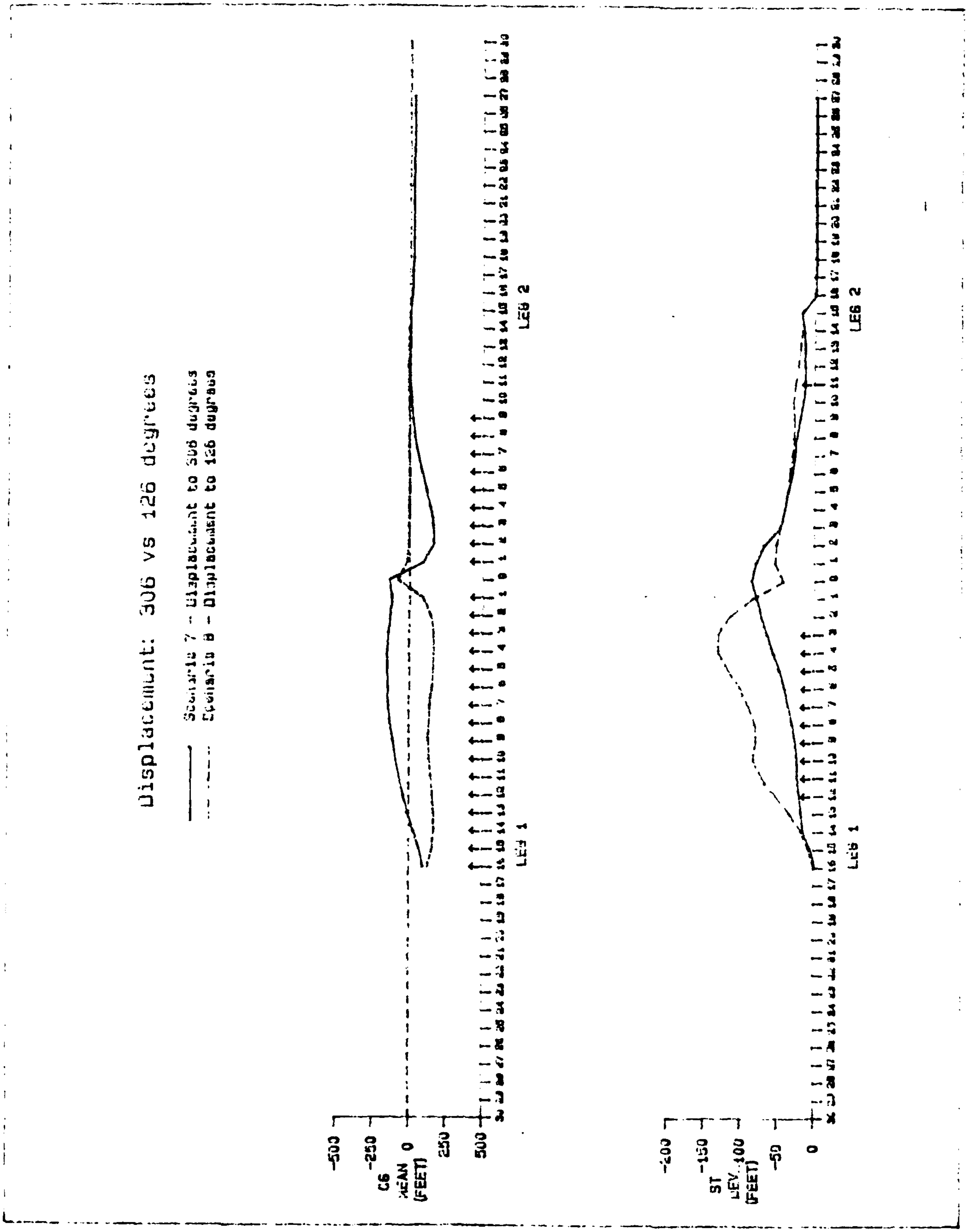
Displacement: 40 yards vs 60 yards
Scenario 4 - 40 yards
Scenario 5 - 60 yards
CG
MEAN
(FEET)
-500
-250
0
250
500
ST
DEV
(FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2



Displacement: 24 yards vs 60 yards
Scenario 5 - 24 yards
Scenario 5 - 60 yards
CG MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
-200
-150
-100
-50
0

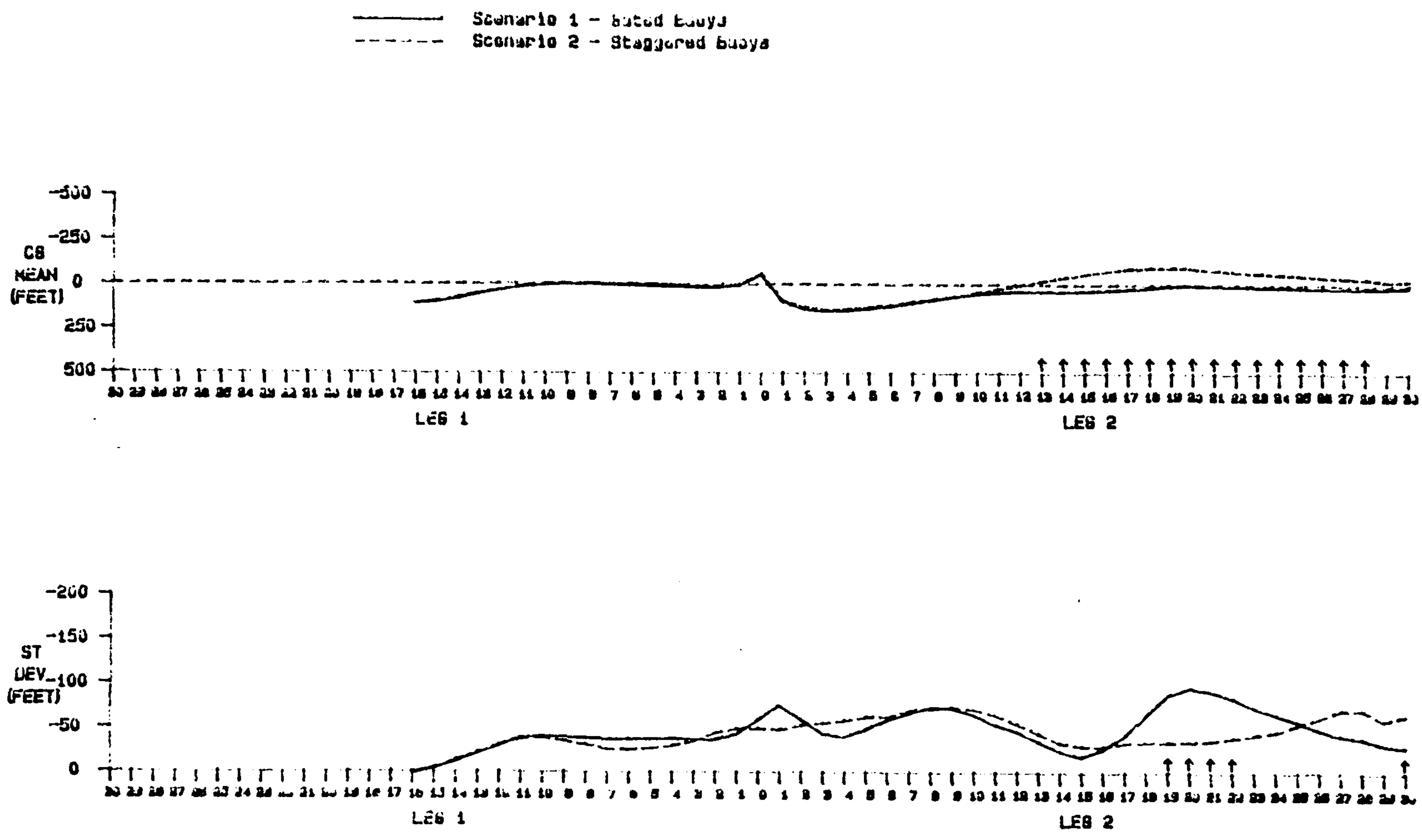
Displacement: 341 vs 161 degrees

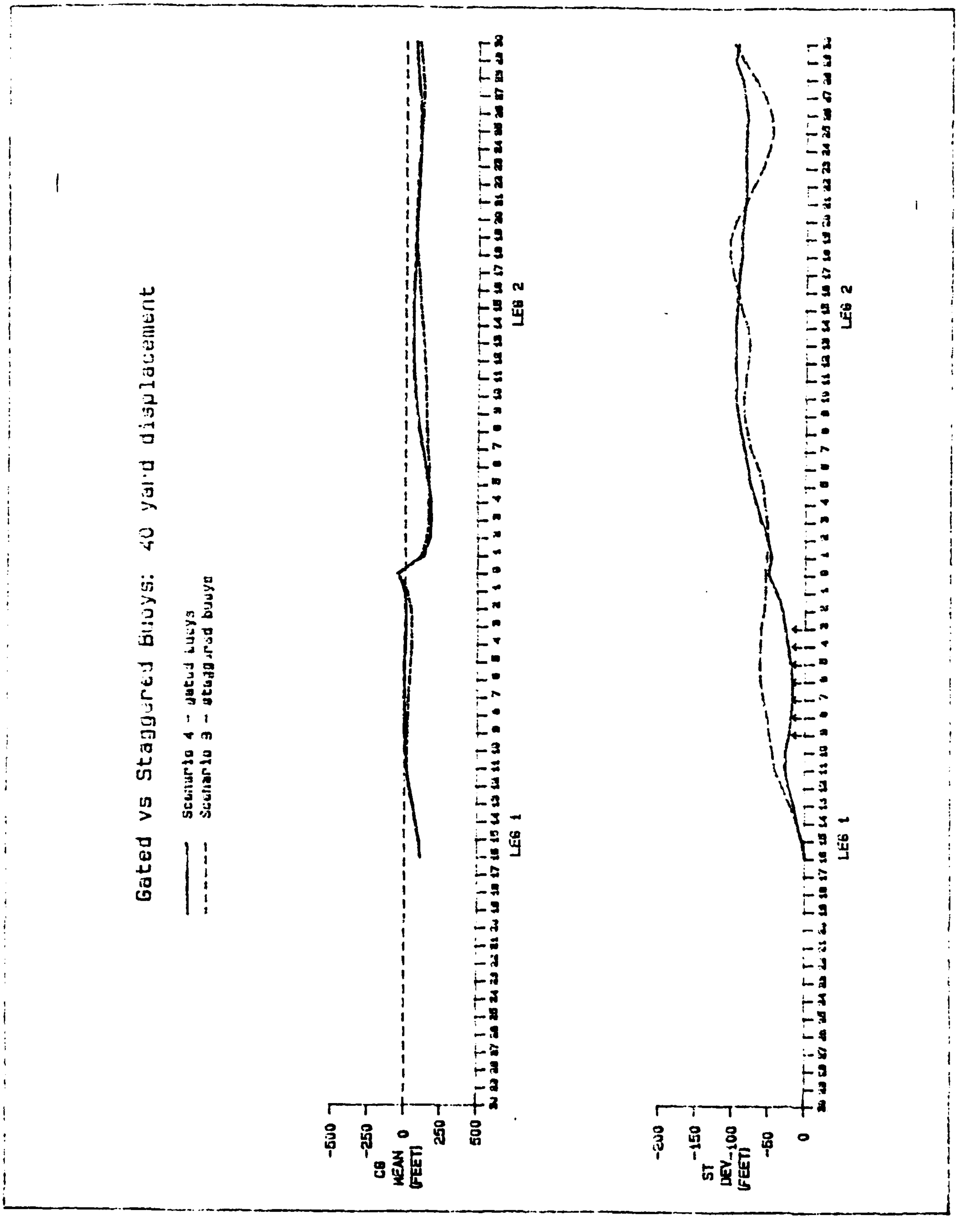




Displacement: 306 vs 126 degrees
Scenario 7 - Displacement to 306 degrees
Scenario 8 - Displacement to 126 degrees
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2

Baseline Conditions: Gated vs Staggered Buoys




Gated vs Staggered Buoys: 40 yard displacement
Scenario 4 - gated buoys
Scenario 3 - staggered buoys
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2

Appendix F

COMPARISON PLOTS FOR INTERIM GUIDELINES

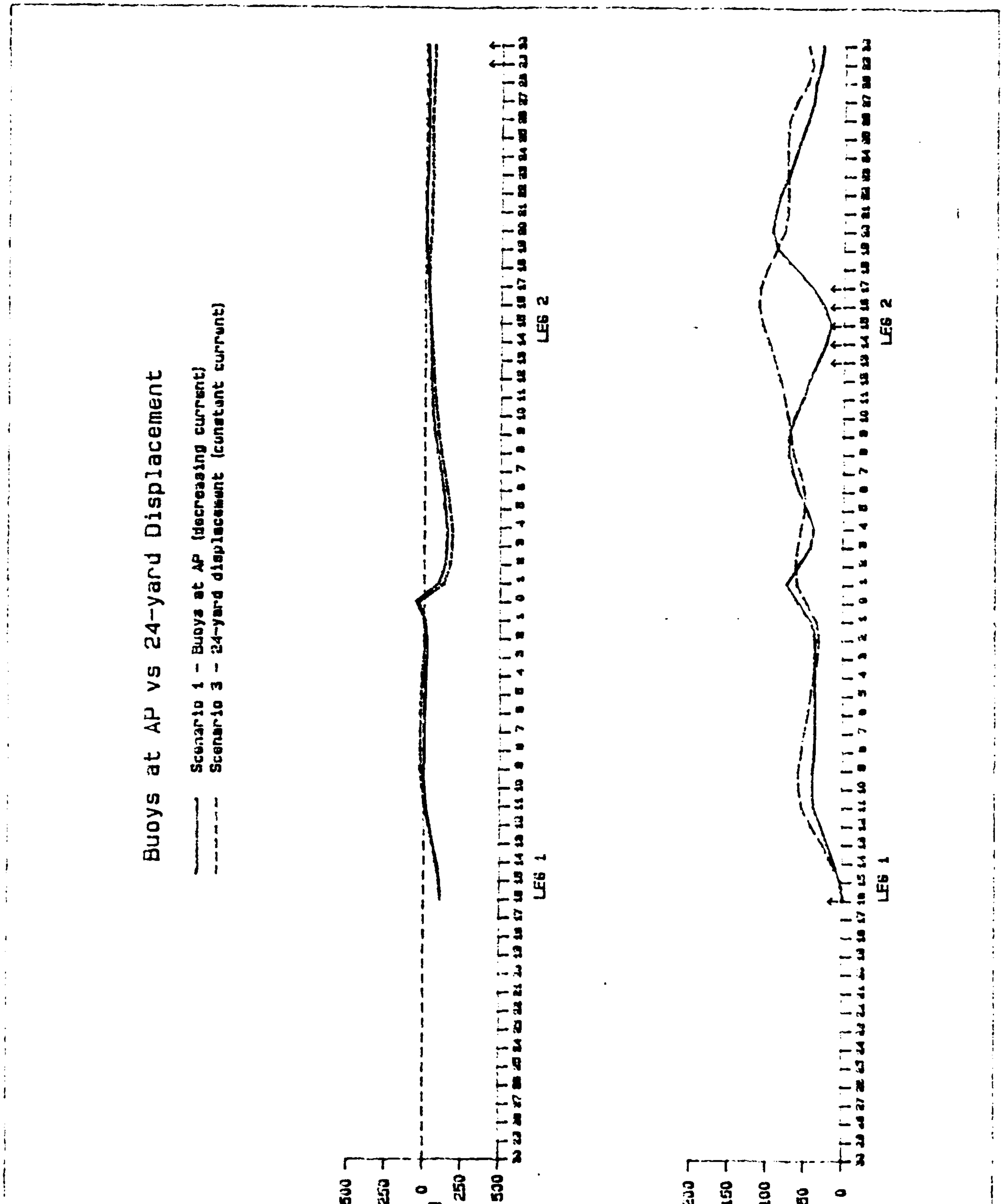
The plots which follow are a graphical representation of the comparisons on which the discussions in Section 6.5 were based. That section was a description of the use of the data to develop the interim guidelines. For each subsection there is a "comparison" plot comparing statistics from the two scenarios. This type of plot has been described in Section 4.3. These comparisons are summarized in Table F-1, which is repeated from the text as a convenience for the reader.

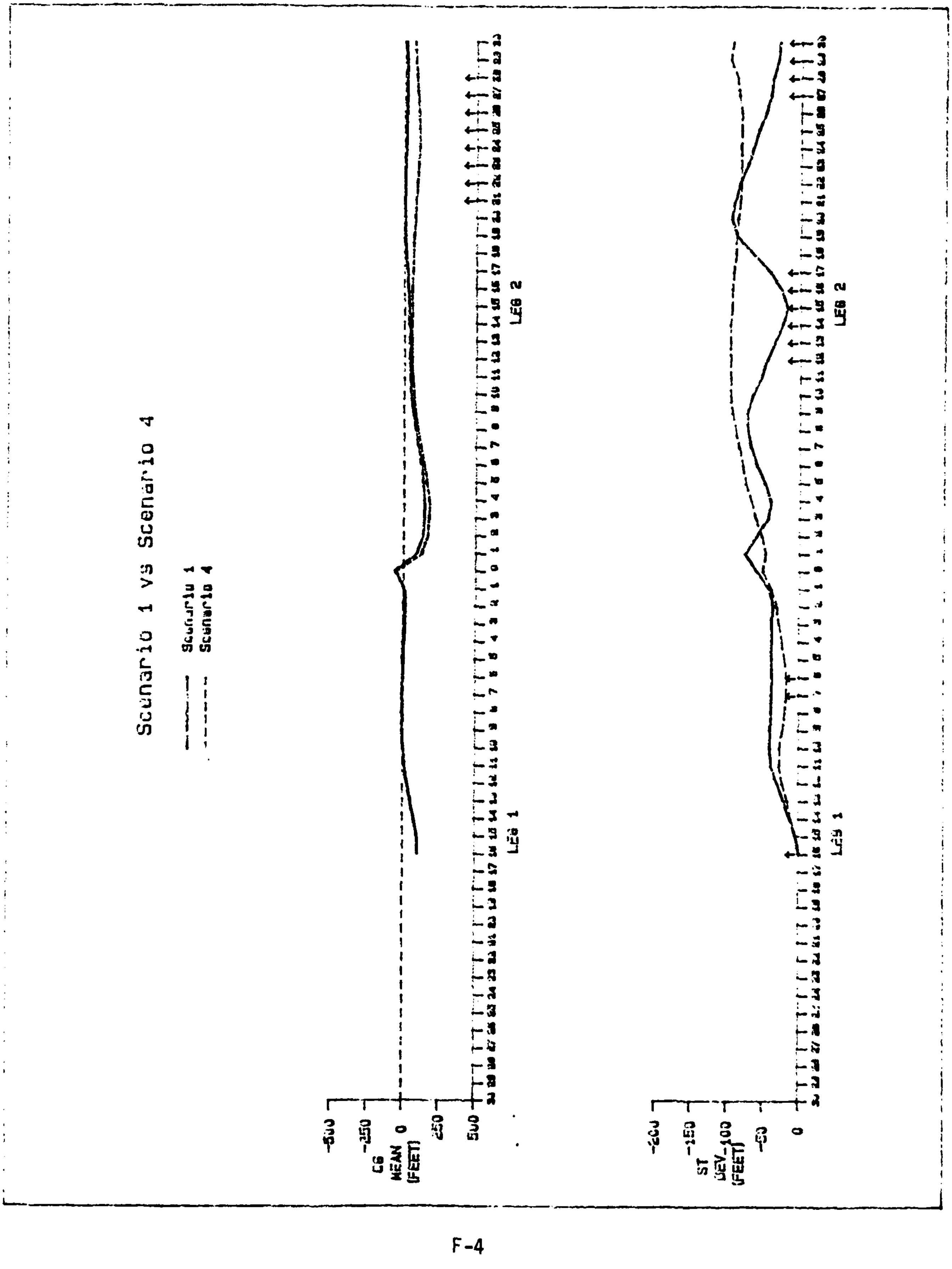
For each comparison there are two sets of axes, one showing the mean and one showing the crosstrack standard deviation as the performance measures. Data is plotted as a continuous unbroken line and a dotted line to distinguish the experimental conditions from each other.

Statistical tests were used to test differences in performance at each data line, to determine if any differences between the conditions were statistically significant. The means were compared using a t-test. The arrows along the axis of the mean plot indicate a difference at the 0.10 level of significance. The standard deviations were compared as variances using an F test. The arrows along the axis of the standard deviation plot also indicate a difference at the 0.10 level of significance.

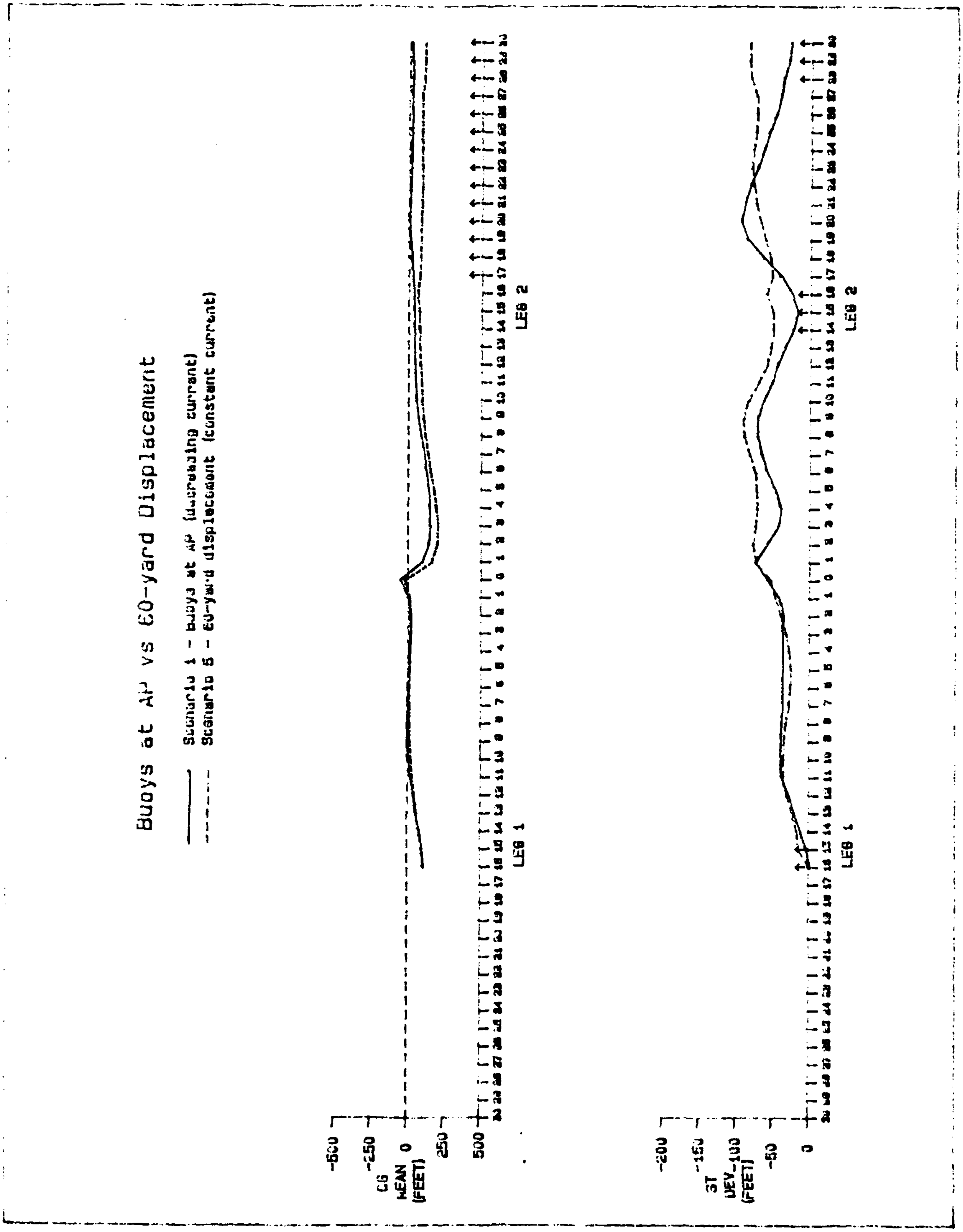
TABLE F-1. ADDITIONAL COMPARISONS SUPPORTING INTERIM GUIDELINES

EFFECT	SCENARIOS
Baseline Conditions Versus Varying Buoy Distances	
Assigned Position Versus 41 Feet Perpendicular Distance	1 vs 3
Assigned Position Versus 69 Feet Perpendicular Distance	1 vs 4
Assigned Position Versus 103 Feet Perpendicular Distance	1 vs 5
Baseline Conditions Versus Varying Buoy/Current Directions	
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 341°T	1 vs 4
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 161°T	1 vs 6
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 306°T	1 vs 7
Fixed Buoys/Decreasing Current to 341°T: Versus Floating Buoys/Constant Current to 126°T	1 vs 8


Buoys at AP vs 24-yard Displacement
Scenario 1 - Buoys at AP (decreasing current)
Scenario 3 - 24-yard displacement (constant current)
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2

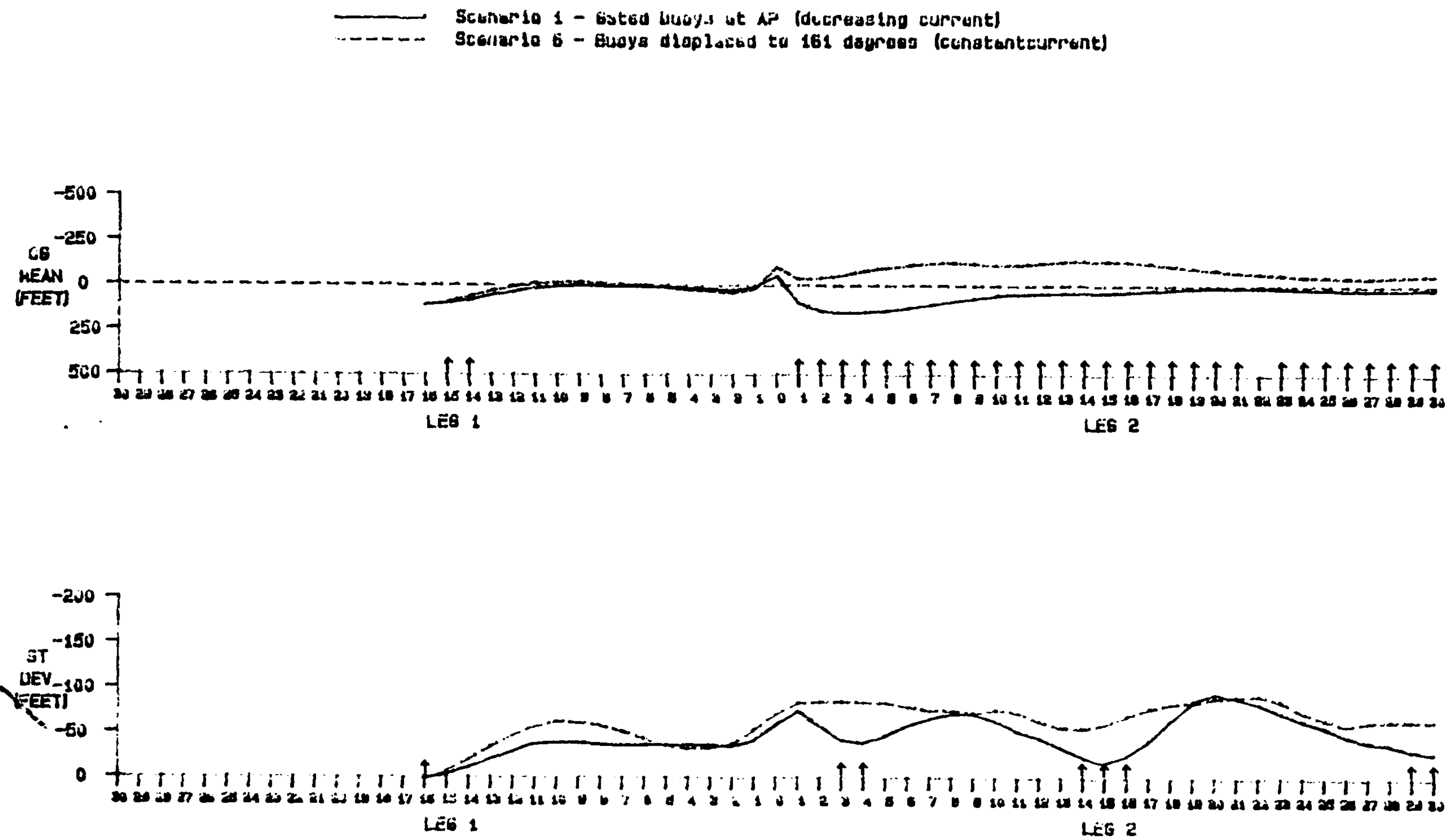


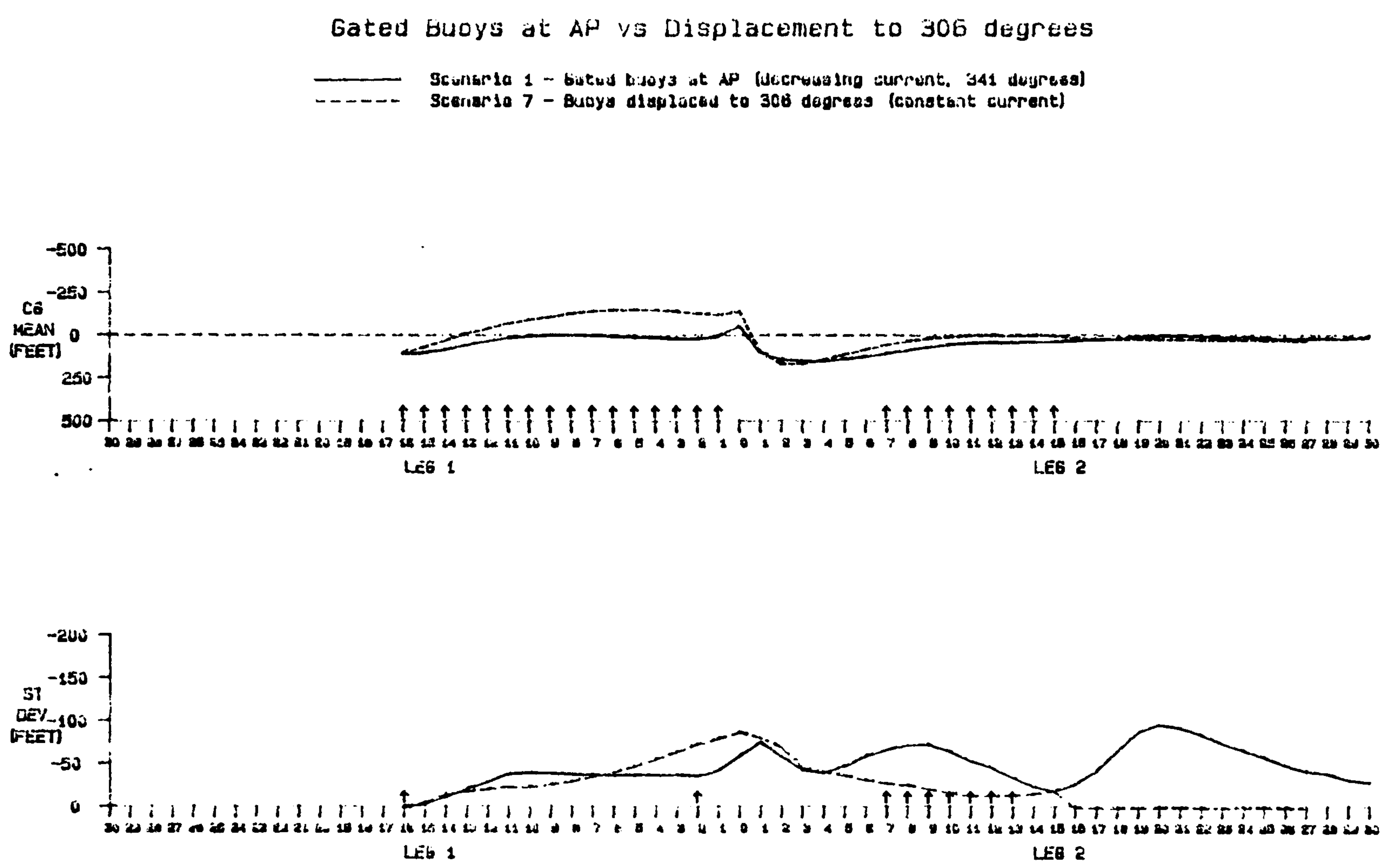
Scenario 1 vs Scenario 4
Scenario 1
Scenario 4
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2



Buoys at AP vs 60-yard Displacement
Scenario 1 - buoys at AP (decreasing current)
Scenario 5 - 60-yard displacement (constant current)
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
-200
-150
-100
-50
0
LEG 1
LEG 2

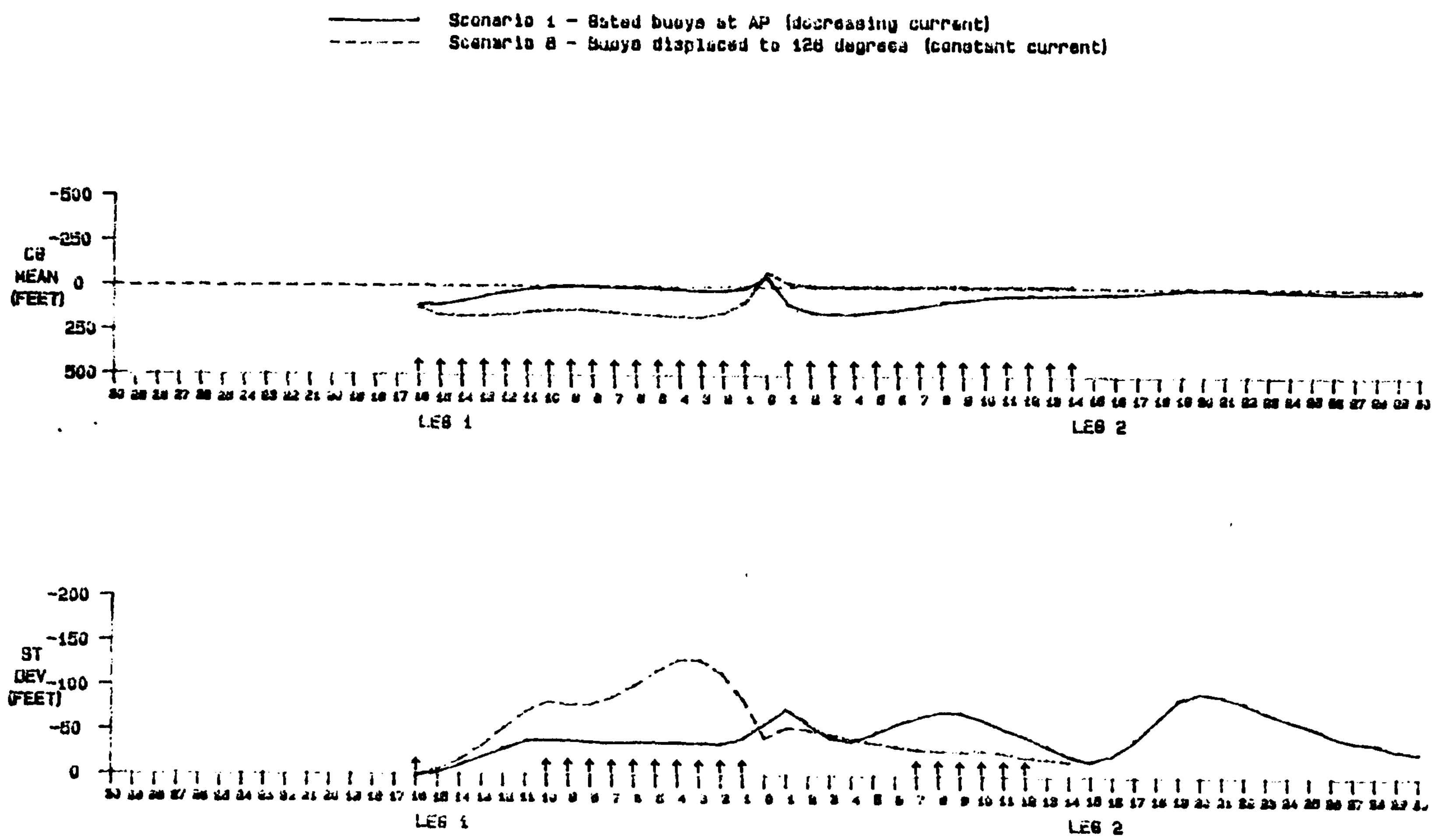
Gated Buoys at AP vs Displacement to 161 degrees





Gated Buoys at AP vs Displacement to 306 degrees
Scenario 1 - Gated buoys at AP (decreasing current, 341 degrees)
Scenario 7 - Buoys displaced to 306 degrees (constant current)
-500
-250
0
250
500
CG MEAN (FEET)
LEG 1
LEG 2
-200
-150
-100
-50
0
ST DEV (FEET)
LEG 1
LEG 2

Gated Buoys at AP vs Displacement to 126 degrees



BIBLIOGRAPHY

Bertsche, W.R., D.A. Atkins, and M.W. Smith. Aids to Navigation Principal Findings Report on the Ship Variables Experiment: The Effect of Ship Characteristics and Related Variables on Piloting Performance. CG-D-55-81, U.S. Coast Guard, Washington, D.C., November 1981. (NTIS AD-A108771)

Brown, W.S., M.W. Smith, and K.G. Forstmeier. Targets of Opportunity Experiment: Short Range Aids/Radio Aids Principal Findings: Waterway Performance Design and Evaluation. CG-D-3-87, United States Coast Guard, Washington, D.C., March 1987.

McNemar, Q. Psychological Statistics. Fourth Edition, Wiley, New York, 1969.

Smith, M.W. and W.R. Bertsche. Aids to Navigation Principal Findings Report on the Channel Width and Related Variables on Piloting Performance. CG-D-54-81, U.S. Coast Guard, Washington, D.C., December 1981. (NTIS AD-A111337)

Smith, M.W., K.L. Marino, and J. Multer. Short Range Aids to Navigation Systems Design Manual for Restricted Waterways. CG-D-18-85, United States Coast Guard, Washington, D.C. 20593, June 1985. (NTIS AD-A158213)

United States Coast Guard. Aids to Navigation Manual - Positioning. *COMMANDANT INSTRUCTION M61500.1A.* U.S. Coast Guard Guard, Washington, D.C. 20593.